J. M. Donaldson.

PRESIDENT 1931-1932

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By J. M. DONALDSON, M.C., President.

(*Address delivered before* THE INSTITUTION, 22*nd October*, 1931.)

I wish first to thank you, as representing the Institution, for the honour you have done me in electing me President. I should, indeed, be lacking in sensibility if I did not feel somewhat overwhelmed, as well as deeply gratified, by the prospect of standing for a short time in the room of such giants as Kelvin, Hopkinson and Ferranti, to name only a few of our illustrious Past-Presidents. One must realize, however, that so high a standard cannot always be maintained, and I can say only this—that, as an ordinary man of small attainments and little achievement, I shall do my best worthily to uphold the credit of this great Institution and to further its aims and objects.

We must all be very proud of belonging to an Institution of such high traditions and with so large a membership, although, of course, it is not by numbers only that the greatness of such a society must be judged. I do feel, however, that the Institution has shown itself broad-based, adaptable, and ready to deal with the increasing activities of the electrical industry.

Two matters are particularly noteworthy, I think, in this connection. In the first place, the formation of the Local Centres has proved a great source of strength and has made available far greater possibilities of personal contact and discussion for the membership at large.

The second point is in regard to the specialized Sections, of which we now have two—the Wireless Section and the Meter and Instrument Section. The tendency to specialize becomes greater and greater as time goes on, but I think everyone will agree that a multiplicity of new societies is very undesirable and a source of weakness. The Council, therefore, showed their wisdom some years ago in starting the Wireless Section and, in more recent years, in taking under their wing a virile society, which has now become the Meter Section and which is full of enthusiasm and energy. There appears to be no reason why this system of special Sections should not be continued where circumstances warrant.

The Council have always been anxious to encourage the Student class and, in my opinion, it is the Students, more than anybody else, who have the most to gain from membership. There has been, in the past, a considerable wastage from this class, which appears to have been checked, and here I should like to refer to the *Students' Quarterly Journal*, which has now been issued for a year and which has undoubtedly succeeded in arousing a great deal of interest among the Students. Those of you who have not seen this publication I would strongly recommend to get a copy, and I am sure that you will find it not only instructive but extremely interesting.

There is one other matter concerning the Institution to which I should like to refer now, and that is the Institution building itself. Most of the members know that this building originally belonged to the Royal College of Physicians and Surgeons, and that it was adapted by us for our requirements at some considerable cost. The membership of the Institution has, however, increased so much, and its activities have grown to such an extent, that it seems likely that in the future some other arrangements will have to be made for our accommodation and for the offering of hospitality to various kindred societies from time to time. The building is on a long lease from the Duchy of Lancaster, and the desirability of a home built particularly for our requirements and on a more permanent basis has always been in mind. A suitable site, however, is by no means easy to find, but it may be that in the near future some such site will be available. Should this be the case, no doubt the Council will consider all the possibilities, in view of the ultimate erection of a worthy and well-designed building in the future.

I am afraid it will be very difficult for me to maintain the very high standard of interest which has been aroused by recent Presidential Addresses. I cannot show you new and improved forms of lighting, as Mr. Paterson did last year, nor intrigue you with such an ingenious use of wireless as was employed by Sir Thomas Purves in the previous year, nor can I expect to arouse such interest as was shown in Sir Archibald Page's discourse, when he gave us in such great detail the engineering details of the "grid," in which everybody was so interested. I am afraid that all I am proposing to do is to make a somewhat dull historical summary of some matters which, in my opinion, have been overlooked in recent years.

It will not cause any surprise that my Address should deal with the subject of electric power supply in this country, since more than half my life has been devoted to this particular branch of electrical engineering.

What I shall have to say will concern in the main the work which has been carried out by private enterprise. This is neither the time nor the place to enter into arguments in regard to the relative merits of public and private enterprise—an unprofitable task at the best. It would, indeed, be unfair to attempt any such thing, inasmuch as the President's Address is not open for discussion. In what I have to say, therefore, I am confining myself to a statement of facts which are apt to be forgotten in these days, when, for some reason, it appears to be fashionable to consider that the solution of all problems lies in public ownership. Before proceeding on such an assumption it is advisable, I think, to study the situation and to discover what considerations in the past have aided or hindered the general supply of electricity in this country.

My Address, then, will deal with the pioneer work of electricity supply and will be divided into three periods, which, to a certain extent, overlap; and I shall not attempt to deal with the whole supply situation but only with those parts which, in their time, presented elements of novelty—indeed, one might almost say, of experiment.

The first period covers the introduction of electric light into the cities and larger towns of the country.

The second section relates to the work of the power companies, when the use of extra high pressure enabled a much wider area to be covered from a single power station, and when the use of electricity for power purposes was becoming an important factor in the situation. This section deals with the introduction of power and light to the industrial districts of the country and, incidentally, to a good many rural districts nearby.

The third section deals with a process which has been going on now for a considerable number of years and which is proceeding at a more rapid rate at the present time, and that is the filling in of the gaps and the building up of what I shall refer to elsewhere as the capillary network of the country.

Part 1.

The Coming of the Electric Light.

It was in 1831 that Michael Faraday made his fundamental discoveries in electromagnetism on which the whole modern practice of electrical generation is based, and, in view of the Centenary Celebrations, it is of interest at this time to see what great results ultimately began to issue from those classical experiments. It was nearly 50 years before such practical results began to flow, and, indeed, it was not until Swan invented the carbon-filament lamp in 1880 that electric lighting in its wider uses became at all possible. Before that date, of course, the arc lamp had been used for the lighting of streets, large buildings and, indeed, some private houses; but the limitations of this method were obvious
was not until the "sub-division of the electric ligh
it used to be called, had been made feasible by S
invention, that real progress was possible.

It must be remembered that it has always
possible to supply electricity to a limited extent w
any legislative powers whatever, and, as long as
mains are laid on private property, there is noth
limit the activities of anybody who wishes to give g
supply. It is also possible for supply mains to cro
public roads as long as this is done overhead,
indeed, in some cases, arrangements were made by
suppliers to open up public roads with the permiss
the local authority. This, of course, was an ur
factory state of affairs, and legislation was the
introduced in 1882 giving undertakers (to use the
name which has always been applied to the memb
the supply industry) the right to open up public
under certain conditions and, naturally, with c
obligations attached to the privilege. Unfortun
however, as has been frequently stated, the Act of
entirely failed of its purpose because it laid down a
of 21 years, after which the undertaking could be
chased by the local authority on terms not altog
definite, but distinctly unfavourable. Whether
unfortunate limitation was due to the personal vi
one man, or whether it represented the feeling
Government at the time, I do not know and it
not to inquire, but it is very singular that this at
should have been adopted with regard to this
industry, when the gas supply industry, which
then been in existence for many years, had never
subject to any such limitation, and it may surprise
of my audience to know that in practically all ca
gas undertaking is held in perpetuity. It is true
there is always a sliding scale connecting prices
dividends, but it would have been perfectly possil
introduce a similar condition into the Electric Lig
Act, since, at that time, current was used for lig
only and the matter would have been relatively si
In later days, as I shall mention further on, a s
scale on a much more elaborate basis has been determ
although, in this case, in connection with underta
which had already been in operation for many
At the present time, two-thirds of the gas in this co
is made by private undertakings, and nobody car
I think, that their service has not been satisfac
although perhaps we may take the credit for h
supplied that element of competition which has ca
them to advance more rapidly than perhaps they
otherwise have done. At the present time, the
Light and Coke Co. is the largest gas supply undert
in the world, and, indeed, its figures of output,
translated into their equivalent electrical units, are
impressive. Anyhow, the Act was so drawn an
effect was to cause stagnation. It may be ar
however, that there was nothing to prevent a m
pality from taking up the business, since they were
no obligation to part with their undertaking af
period. This is quite true, but we forget that the pr
sound financial position of electric supply underta
is one which has only recently been attained. I
early days the business was highly speculative and,

before the War, although progress had been good and results on the whole satisfactory, the financial position of the industry as a whole was not particularly good. During the War and in the slump following it, most undertakings suffered very serious relapses, in common, of course, with other business, and it is only in the last few years that electricity supply has reached what one might call the "gilt edged" stage. In the early days, however, the position was entirely different, and no prudent municipality would have been prepared to adventure the ratepayers' money on an enterprise fraught with so much difficulty and involving such heavy financial risks. For this attitude nobody can blame the municipalities, and it is the framers of the original Act who must be convicted of short-sightedness.

The Act of 1888 altered the period of purchase from 21 to 42 years, and this gave an immediate impetus to enterprise. Before this, however, some bold companies had started electricity supply in a small way, but not much was done until shortly after the passing of the second Act.* Table 1 gives a list of some cities and larger towns where the supply of electricity was inaugurated by a company and subsequently taken over by the municipality, presumably after the undertaking had been sufficiently established. On what terms these undertakings were taken over I do not know, but, whatever was paid, one can be certain that the purchasing undertaking received a good bargain, although nobody at that date could have anticipated the enormous strides in production which subsequently took place.

TABLE 1.

Place	Supply begun by company	Taken over by local authority
Brighton	1882	1891
Eastbourne	1882	1900
Hastings	1883	1898
Liverpool	1883	1896
Glasgow:—		
Muir, Mavor and Coulson	1884	1892
Kelvinside Electric Co...	1893	1899
Birmingham	1891	1900
Southampton	1891	1896
Sheffield	1892	1899
Preston	1892	1922
Hove	1892	1913
Leeds	1893	1898
Norwich	1893	1902
Woolwich	1893	1902

It will be seen that in nearly all the larger centres of population (and, indeed, it was only in such centres that electric lighting appears to have been considered a possibility in the early days) it was private enterprise which took the initiative, and it may perhaps be surprising to some of us now to look back on the time when all the great cities in this country were supplied by companies. In some cases the supply was inaugurated without the formality of obtaining a Provisional Order. This was, for instance, the case in the central part of Glasgow.

It will be noted that London does not appear in this list. The reason is that the major part of "Central London," to use a loose expression, was supplied in the first instance by private enterprise and is still so supplied, with the one exception of St. Marylebone, which was taken over by the local authority some years ago. The position in London was always very peculiar, and the authorities in their wisdom introduced a system of competing companies, with the idea, no doubt, of obtaining cheaper and more satisfactory supply. Not only so, but for some reason, which appears rather obscure at the moment, they insisted on these competing companies having different systems, i.e. one should be direct current and the other alternating. Experience has shown that this form of competition has not, in the long run, produced the results intended, since, from the nature of the case, a great deal of expenditure must necessarily be duplicated, and ultimately the consumer must pay for this.

In 1930, however, all these London undertakings were due for purchase by the controlling authority, which was at that time the London County Council, and, after a considerable amount of inquiry, the decision was reached that the companies were to be given a further lease of life of 40 years under strict conditions in regard to the relation of price and profits. The conditions imposed were necessarily of a novel character and might perhaps be improved after experience, but in the result the position has been stabilized and good results seem likely to accrue.

The position in London which was caused by the probability of purchase produced two strong power-station groups, whose position is set out in the two Acts of 1925 entitled "London Electricity (No. 1) Act, 1925" and "London Electricity (No. 2) Act, 1925." The London Power Co. (which is not a power company in the strict Parliamentary sense of the term) has been carrying out in a quiet and unostentatious manner a remarkable work of unification and consolidation. The company controls and has linked up power stations at Deptford East and Deptford West, Bow, Grove-road, and Acton-lane, Willesden; and the new Battersea station which is in process of erection will, of course, be linked up likewise. The combined energy output of this group of stations amounted for 1930 to 819 millions of units and the maximum demand was 283 400 kW. The other group consists of the County of London Co. and its allies and the City of London Co., between whom there is liaison, but the companies retain their independent entity. The County of London Co.'s main power station is at Barking, where approximately 240 000 kW of plant is now installed, and it is at the present time the largest power station in the United Kingdom. A further extension of 150 000 kW has been authorized. The total sales of the County of London Co. for the year 1930 amounted to 448 million units and the demand was 157 800 kW, although in this case a considerable proportion of the output was sold outside London.

Let us now praise famous men. The younger generation is perhaps rather apt to smile at the efforts of the pioneers, when so-called large units would now be hardly big enough for one of the exciters of the modern mammoth generating sets and would certainly be ridiculously small for the "house" sets of a modern station. It is not, however, the size which marks the value of achievement, and it is difficult for us to realize now the extraordinary difficulty under which these pioneers laboured. We had Ferranti, with his tireless enthusiasm and extraordinary vision, working on the many new problems which had to be faced and which involved, for the most part, the invention and manufacture of entirely new apparatus. At Deptford, Ferranti worked out and put into practical use all the vital features of the modern electric supply system—a power station site chosen for the ease of obtaining cooling water and cheap coal, situated some distance from the centre of the load, an extra-high-tension transmission enabling the power to be transmitted efficiently to the load centre, and the use of large (and they were, for their time, very large) units of generating plant.

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* The first municipality to give a supply of electricity appears to have been Bradford, which started in 1889. Newcastle (company) followed in 1890 and then a considerable number of towns, including Manchester, started in 1893.

At the west end of the town Crompton was working on different lines and was the great protagonist of the direct-current system, as opposed to Ferranti with his alternating current. It was Crompton who gave us the idea of load factor, which now forms a necessary criterion in all modern tariffs. What these pioneers had to face in the way of difficulties can only be dimly appreciated by us now that all these matters are commonplace and routine. In those days, however, a supply of electricity was a high adventure. It is true that other men have laboured and that we have entered into their labours; and we should not wish this debt we owe them to be forgotten.

Part 2.

THE WORK OF THE POWER COMPANIES.

It is probably not realized by everybody what a very important work has been carried out by the great power companies in this country, but it is true to say that the foundation of the power companies marks the most important advance in the general distribution of electricity in this country after its first introduction. I could have wished that one of our past-presidents—Mr. Woodhouse, who may be called the doyen of the power companies' engineers—had had to deal with this matter, but I am giving in a somewhat compressed form the leading facts about this very important development, with which I am proud to have been connected in a minor way.

The consideration of this matter follows very naturally from the practical results obtained in the earlier London developments of the electricity supply companies. The difficulty of municipal or, perhaps we should rather say, parish boundaries was soon felt, and, indeed, this still remains one of the barriers to widespread distribution, whether it be of electricity, gas, water, drainage or the like. The two former commodities are particularly affected, as they are not concerned with differences in levels, which may otherwise determine suitable boundaries for the handling of flowing liquids.

In the second place, it became very clearly evident that the City of London, for instance, was no place in which to build a power station, even in those days when power stations were not very big, and Ferranti realized quite early that plenty of room was necessary, that the station ought to be near condensing water in considerable quantities, and that there should be facilities for obtaining coal and removing ashes. Further, land in the centre of London is, of course, extraordinarily expensive. Ferranti got over the difficulty with his Deptford power station by taking the mains along a private railway wayleave, although it was in his mind at one time to use overhead lines. The City of London Co., when they built the Bankside station, obtained an Order for two parishes of Southwark, in one of which the power station was situated, and had merely to cross bridges in order to get into their territory. This is the cause of the extraordinary situation that the Southwark municipality does not supply in the whole of their area. The Charing Cross and City Co. originally had a station in Lambeth on the south side of the river, outside their area of supply, and they made some confidential and, I fear, illegal arrangements with the then Lambeth Vestry to enable them to take the cables along the Commercial-road and then on to private property and so across the river. So doubtful were the company of the legality of their proceedings that they took the trouble to start the work on Good Friday, 1895, and to work right through the holiday so as to prevent the possibility of an injunction. Later on, however, the Charing Cross and City Co. erected a station at Bow, and, in like manner, the Metropolitan Electric Supply Co. put up a station at Acton-lane in Willesden, but, of course, they had to get special authority from Parliament for doing this.

In 1898 a very important Committee, known as Lord Cross's Committee, was appointed, and its terms of reference were to consider, among other things, whether special powers should not be given "for the supply of electrical energy over an area, including districts of numerous local authorities, involving plant of exceptional dimensions and high voltage and under what conditions ought such powers to be conferred upon promoters seeking to supply electrical energy in bulk to other undertakers and not directly to consumers." At this time, the possibilities of extra-high-pressure transmission were visualized, also the necessity of large power stations to enable current to be generated more cheaply, and the desirability of making it possible for large power users to obtain current at low rates. The result of this Committee's deliberations was to find that such power supply organizations were desirable and that they should be given perpetual powers of supply. It is this latter condition which is the distinguishing feature of the power company, and, without such a concession, it would certainly have been impossible to have carried out the work which has actually been achieved.

Now it is important to note that there was no general Act of Parliament establishing power companies at all, but that an influential Committee considered the matter, took evidence and, on the basis of its findings, various private Bills which were submitted to Parliament received the Royal Assent, and so the power companies came into being. Broadly speaking, their functions were to supply power in bulk to various distribution authorities and also to supply power direct to large power consumers. In all cases, such companies had within their boundaries large and small municipalities, and usually they were definitely prohibited from supplying power in any of these areas, while in some cases they were restricted by what is known as the "Kitson" clause, which came, however, to very much the same thing.

It hardly needs pointing out that to organize a system of this kind is by no means easy, since one has no nucleus from which to start. In other words, it is quite a different problem from that of starting a supply in a big town, or even a small town, or again from extending the distribution boundaries of a town where a supply is in existence. Moreover, prospective power users were much more wedded to their old systems of independent generation; and, indeed, it is even now a matter of pride to some firms that they have a steam engine which has been working for, say, half a century. In these circumstances, it is not surprising that although a number of Bills were put before Parliament and eventually became Acts, there was no very great desire among promoters to deal with this class of business. Some of the Acts were, indeed, hawked round the country for a considerable time, and in all cases it was not for many years that a dividend was paid on the ordinary shares. Consequently, although at the present time the shares of power companies stand very high in the market owing to the good results which have been obtained, this has been the result of very arduous work in the past and a great deal of sacrifice on the part of those who originally put money into the business. In considering the present prosperity of these undertakings, one has to bear in mind the "lean" years which most certainly preceded the present state of mild prosperity and stability.

The position at about the end of the last century was that, owing to the recommendations of Lord Cross's Committee, the way was left open for the supply of power on a large scale, and it was obviously to the industrial districts of the country that attention was first turned. Fig. 1 is an outline map of Great Britain, whereon the density of population is indicated by shading, and it is natural that these densely populated areas are the centres of manufacture.

Fig. 2 shows the areas of the various power companies, and here it must be repeated that the true power company is one which has perpetual powers; only such companies are here considered.

By superimposing Fig. 2 on Fig. 1, it will be seen how very closely the power companies' areas follow these industrial regions. In the north we have the Clyde Valley Co. working in the neighbourhood of Glasgow, with its shipyards, steel furnaces and the like, while towards the west and in the middle belt of Scotland are the Lothians Electric Power Co., the Scottish Central Electric Power Co., and, in the "Kingdom of Fife," the Fife Electric Power Co. This covers the industrial belt which stretches right across Scotland from the Forth to the Clyde. Passing further south, we come upon the Newcastle Electric Supply Co. and its allies in Durham—a district again noted for shipbuilding, steelworks, coal mines and heavy industry generally. Further to the west we have the "dark Satanic mills" of Lancashire, with its teeming towns, cotton mills and coal mines. In the centre, the domain of the Yorkshire Power Co., with its mills, coal mines and heavy industries; in the central part of England, the Shropshire and Worcestershire Co., including the great metal-working district round Birmingham, as well as very large country areas; the Leicestershire and Warwickshire and the Derbyshire and Nottinghamshire Electric Power Companies also in the Midlands; while the North Metropolitan Electric Power Co. takes care of the district in the north of London, which is very rapidly becoming industrialized owing to the tendency of industries to move southwards. In the east, the Kent Power Companies, dealing largely with cement works and the like, and, in the extreme south-west, the Cornwall Power Co. with its specialized mines, at present working under very depressed conditions. The great coal district of South Wales is covered in the main by the South Wales Electric Power Distribution Co.; while North Wales has its own power company. The latter is the only area which is not densely populated, but, of course, there are water-power resources, while quarries and the like take up part of the supply.

Before exhibiting a table showing the extent of the power companies' operations, it would, I think, be only fair to refer to the pioneer work carried out in Newcastle. The Newcastle Electric Supply Co. remains easily the largest of the companies and, with its allies, it has the most widespread territory. The operations of the company really began in 1901, when Lord Kelvin inaugurated the supply from the Neptune Bank station. At the time, this station was considered to be a very large one, but, in point of fact, the main generating units consisted of four 700-kW generators running at 100 r.p.m.—an installed capacity of between 2 000 and 3 000 kW. The present installed capacity of the company is over 300 000 kW, and this gives a measure of the growth of the business. It is interesting to note in this connection that the engineer of the original scheme, and, indeed, the consulting engineer to the company now, is Mr. C. H. Merz—our latest Faraday Medallist.

With these introductory remarks, I shall now draw attention to Table 2, which is worthy of some study and which gives in a compact form the leading particulars of the work done by this group of supply undertakings.

After the name in the first column, the second column states the date of the original and principal Acts, to give an indication of the time when it was possible for work to be started.

The third column gives the territory covered in square miles, and it will be noted that the total for all the companies is over 24 000 square miles.

The next column gives the maximum demand on the system in 1930, the total for that year being very nearly 700 000 kW.

Column 5 contains the names of the principal power stations, which, in point of fact, are all "selected stations" under the "grid" scheme, and this list includes some of the most economical stations in the country.

Column 6 shows the plant capacities of all the stations, while the next two columns indicate respectively the mileage of feeder mains and the number of transforming centres. These two figures were selected with a view

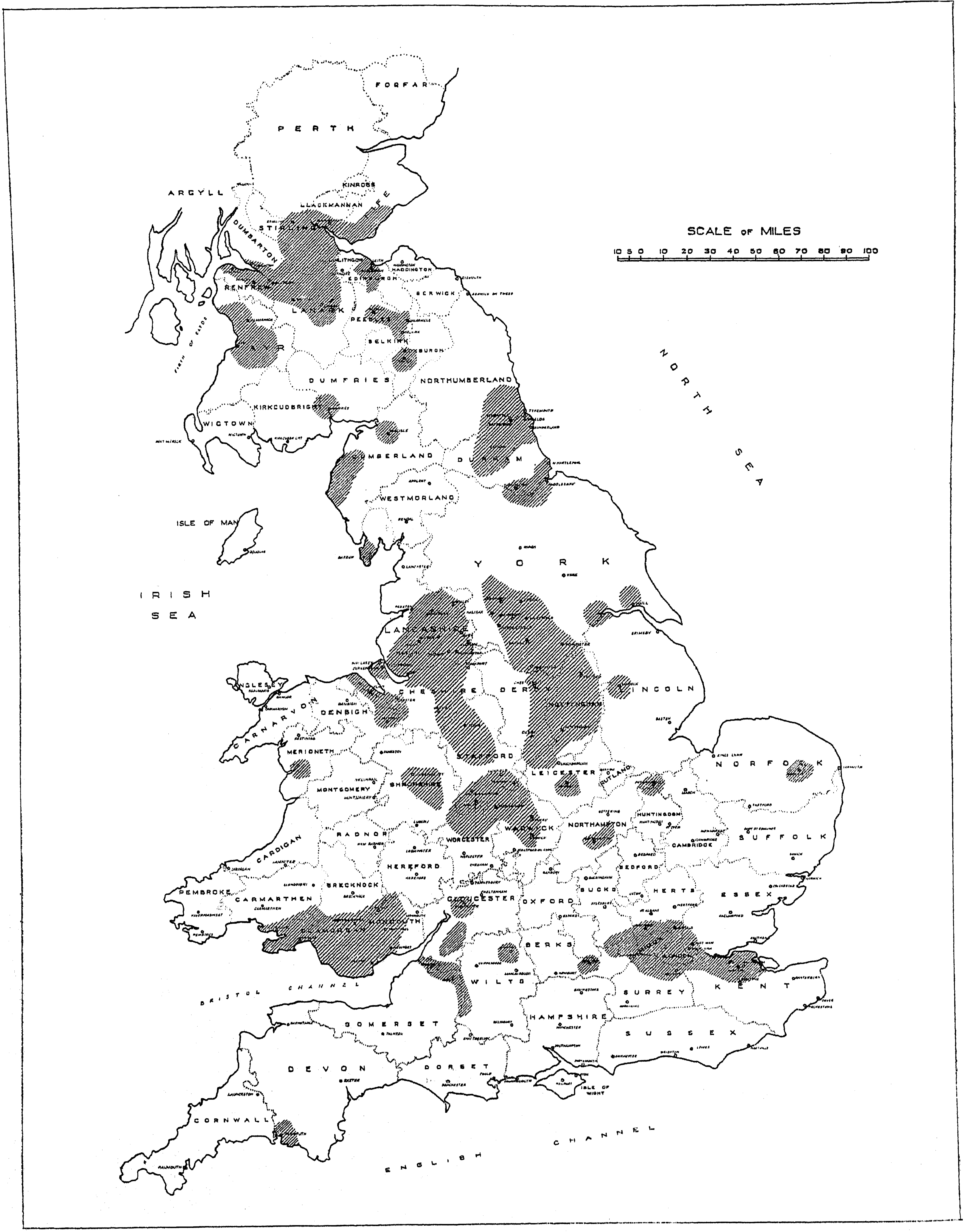

FIG. 1.—Industrial areas.

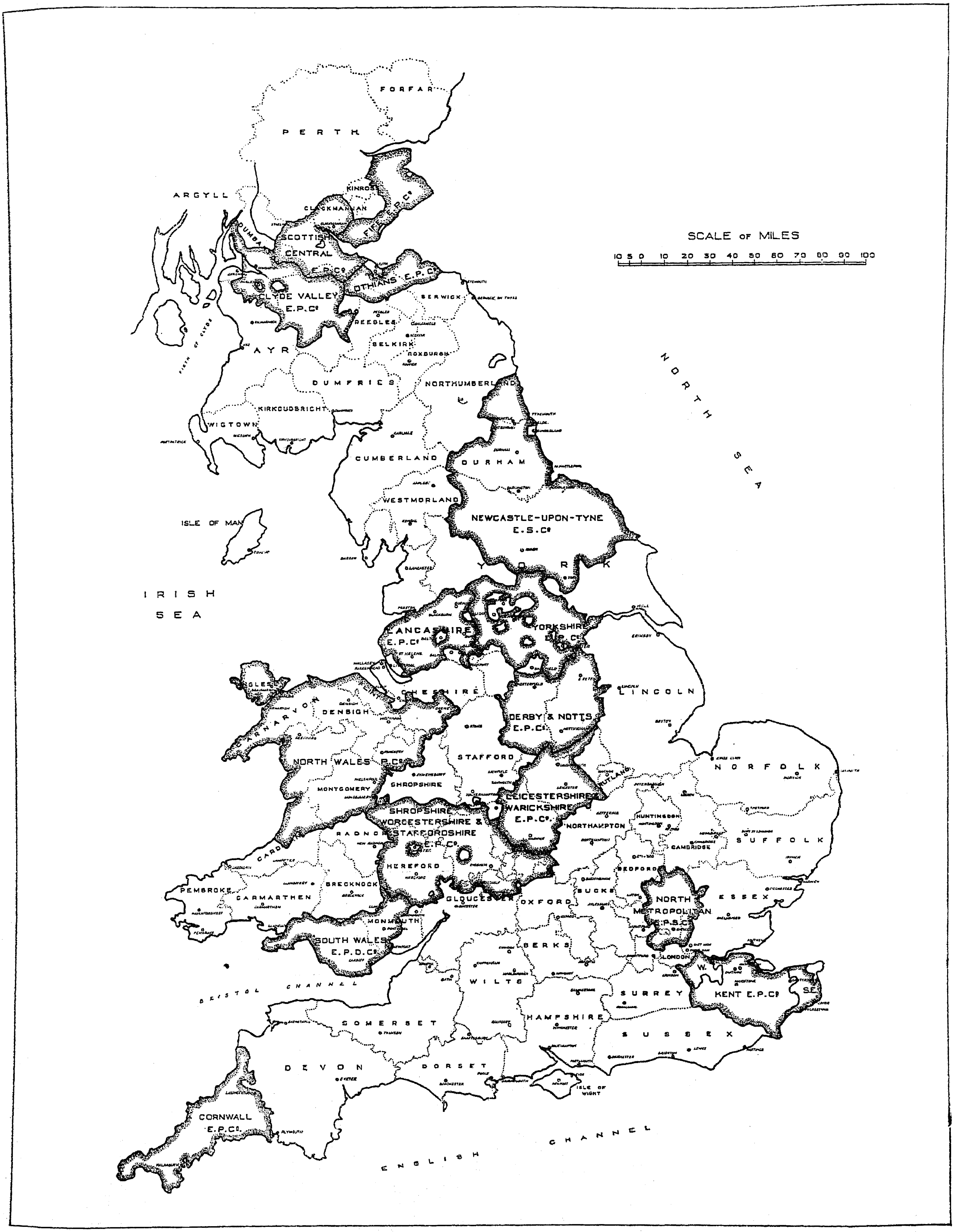

FIG. 2.—Power Companies' areas.

TABLE 2.

Power Companies.

Name of company 1	Main Act or Acts 2	Total territory 3	Maximum demand, 1930 4	Selected power stations 5	Total plant capacity 6	Length of feeder mains 7	Number of transformer centres 8	Total units sold, 1930 9	Average price per unit, 1930 10	Capital expenditure, 1930 11
		sq. miles	kW		kW	miles		units	d.	£
Clyde Valley Electrical Power Co.	1901–1924	1 033	75 150	Clyde's Mill and Yoker	128 270	563	372	254 469 477	0·72	4 249 679
Cornwall Electric Power Co. ..	1902	1 260	4 614	Hayle	16 800	186	44	17 479 197	1·22	534 870
Derbyshire and Nottinghamshire Electric Power Co. ..	1901–1929	1 570	31 000	Spondon	64 000	964	273	114 587 481	0·81	2 602 537
Fife Electric Power Co. ..	1903, 1930	502	8 160	Dunfermline	16 550	221	202	23 005 828	1·44	992 747
Kent Electric Power Co. ..	1902–1911	1 128	20 770	Nil. Bulk supply from County of London Elec. Supply Co. (Barking)	Capacity of Barking 237 500	159	62	112 259 350	0·54	947 453
West Kent Electric Power Co.	1909	140	7 800	Nil.		69	38	26 404 145	0·92	420 406
South-East Kent Electric Power Co.	1902–1911	170	363	Nil.		10	9	366 620	—	71 454
Lancashire Electric Power Co.	1900	1 200	80 280	Kearsley, Padiham and Radcliffe	162 000	595	309	220 647 174	0·61	4 732 791
Leicestershire and Warwickshire Electric Power Co. ..	1902	1 340	28 548	Avon and Nutt's Lane	26 000	458	309	76 641 349	1·17	2 098 430
Lothians Electric Power Co...	1904–1929	734	2 474	Nil	Nil	162	141	8 726 158	1·60	415 829
Newcastle-on-Tyne Electric Supply Co.	1902	1 041	173 660	Carville, Dunston and North Tees	311 900	525	321	647 591 975	0·72	7 366 293
Cleveland and Durham County Electric Power Co.	1901, 1928	3 433		Nil	Nil	215	247			515 682
County of Durham Electric Power Supply Co.	1909	251		Nil	15 668	420	255			1 441 281
North Metropolitan Electric Power Supply Co.	1900–1927 Consld. Act, 1928	632	95 350	Brimsdown A. and B. Willesden	106 100	790	421	228 663 310	0·80	6 212 821
North Wales Power Co. ..	1904, 1923	4 085	22 700	Nil	38 700	521	200	78 611 206	0·70	3 417 735
Scottish Central Electric Power Co.	1903, 1930	400	11 400	Bonnybridge	28 080	164	145	42 774 157	0·89	823 635
Shropshire, Worcestershire and Staffordshire Electric Power Co.	1903–1930	2 550	55 780	Stourport and Smethwick	93 000	612	510	115 315 161	0·85	5 248 218
South Wales Electric Power Distribution Co.	1900	1 034	17 093	Pontypridd	55 000	252	194	75 437 037	0·72	1 987 324
Yorkshire Electric Power Co.	1901	1 800	64 310	Barugh, Ferrybridge and Thornhill	89 000	1 234	717	194 995 437	0·78	5 076 859
Total	—	24 303	699 452	—	1 388 568	8 120	4 769	2 237 975 062	0·76	49 156 044

to giving an idea of the extent to which the territory had been covered. The length of feeder mains includes everything except distribution mains, whilst it is important to note the number of points from which supply can be obtained, as this is a measure of the accessibility of the product which the undertakings have to sell. It will be understood that in some cases these points will be single-transformer centres supplying, possibly, an isolated house or farm; or, indeed, they might be larger centres supplying power to a large or small works; or, again, they might be substations in some densely populated centre, supplying several hundred consumers. I think, however, that these two figures taken together give a fair criterion of the extent to which supply has been made available. The total mileage of feeder mains amounts to over 8 000, and the number of transforming centres to nearly 5 000.

Column 9 gives the number of units sold in 1930. This is an important figure because the real measure of the utility of an undertaking must eventually be the amount of current which it sells. The total figure for the whole group is well over 2 000 millions.

The next set of figures, namely, the average price per unit in 1930, requires some explanation, and too close a comparison must not be made between the various companies, apart from the fact that there is a considerable variation in the price per ton for which the coal can be purchased. In most cases the figures represent what might be called a "bulk supply price," i.e. the figure obtained by adding the money received from authorized distributors for purchases in bulk to the revenue from large power consumers, and dividing this by the number of units sold. Certain undertakings, however, return a higher average by including the price obtained from consumers, small and great, supplied through an Order held by the company. Practically all the companies operate, in addition to their power business, Orders of the usual type, which are subject to purchase; and while, in some cases, these Orders are treated separately as individual undertakings or as a group of undertakings, in other cases they are included with the power business.

The final column shows the total capital expenditure on the various undertakings, and this reaches a total of about 50 millions.

It must not be thought, however, that these companies contented themselves merely with bulk supply, since, as indicated above, most of them operate separate Orders in their areas, and in some cases they are enabled by the terms of their Acts to deal with distribution work without an Order. This is the case in part of the North Metropolitan Co.'s area and it has undoubtedly proved of very great benefit to all concerned, inasmuch as the district can be developed as a whole without any regard to local boundaries and the possibility of separate purchase. Moreover, by amalgamating a large number of districts in this way, it is possible to give a much better service at a cheap rate.

It will therefore be found that in the power companies' areas a very large amount of penetration into rural districts has been carried out, and this is going on at an increasingly rapid rate. I deal with this subject in the third part of my Address and I shall therefore merely draw attention here to the fact that it was the power companies who initiated this side of the business.

There is, however, one point to which I think attention might be called, and that is the possibility of linking up organizations of this character, covering, as they do, very large areas. To illustrate this, I have shown in Fig. 3, in a rather sketchy way, the interconnections between the North Metropolitan Electric Power Co. and its neighbours. I have included also the area of the Bedfordshire, Cambridgeshire and Huntingdonshire Electricity Co., which is not a power company in the strict sense of the term, as it is purchasable under certain conditions; but it is managed in the same way, and its area and that of the North Metropolitan Co. are run together. The point I wish to make is the manner in which it has been possible, to the mutual advantage of the parties concerned, to link up with almost the whole of our neighbours. There is a 20 000-kVA link between the Brimsdown station of the North Metropolitan Co. and the Barking station of the County of London Co.; a small and old-established link, at the present time about 3 000 kVA, with the Hackney Borough Council; with the London Power Co., by arrangement with the Central Electricity Board, about 30 000 kVA; with Watford Corporation, by a cable capable of supplying 6 000 kVA; with the Luton Corporation through a 20 000-volt cable with a capacity of 2 500 kVA. The Bedfordshire Company itself was originally supplied from the North Metropolitan Co., but it now takes the bulk of its supply from Bedford through the first section of the grid to be put into commercial use in this country, while a small part of the Bedfordshire Company's area in the north is supplied, again through the good offices of the Central Electricity Board, from Peterborough. As a matter of interest, it may be mentioned that the grid lines are shown in the diagram.

The subject is introduced to show the possibilities of interconnection, sometimes on the reciprocal basis and sometimes not, with the idea of economizing plant. I believe, indeed, that it would have been quite possible for the power companies acting together to have achieved much the same object as will be obtained by the grid, but by a different and cheaper method. I am not saying, however, that this would have been politically possible. I do not think it would have been, since it is, unfortunately, practically impossible to persuade people to do of their own accord what would be to their undoubted benefit, and the somewhat drastic methods of the 1926 Act were probably necessary in order to secure an all-round utilization of the country's resources.

Part 3.

COUNTRY PENETRATION.

I have already indicated the beginnings of the supply of electricity in this country and I have tried to show the important work which was done, and is still being done, by the power companies to bring the benefits of electricity to large areas in this country; but there are still certain areas on which I have not touched. In addition to the pioneer work in the big towns, a large number of the smaller towns now obtain the benefits of electricity, and this work was, I think, generally done by

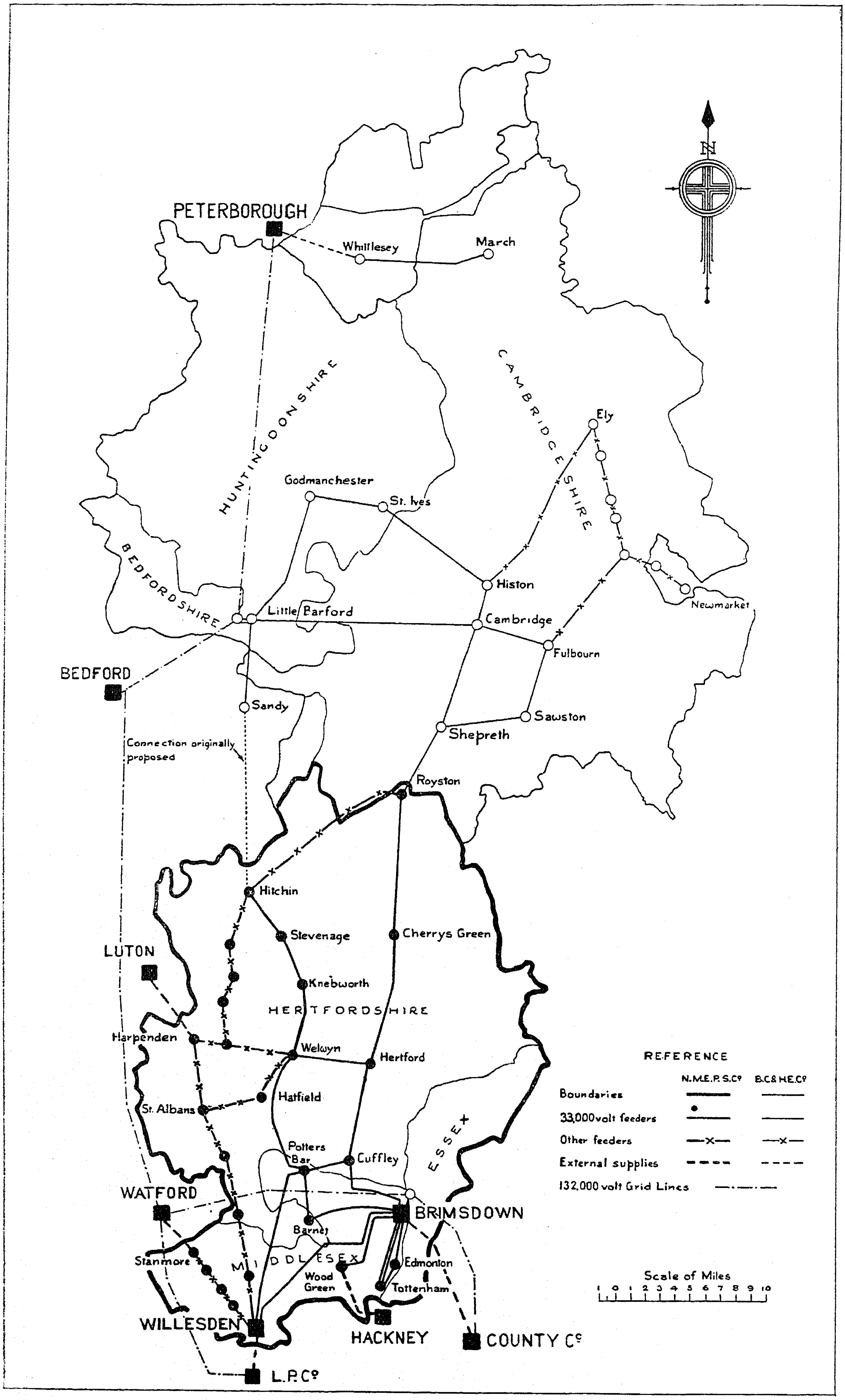

Fig. 3.—Linking-up connections of a power company.

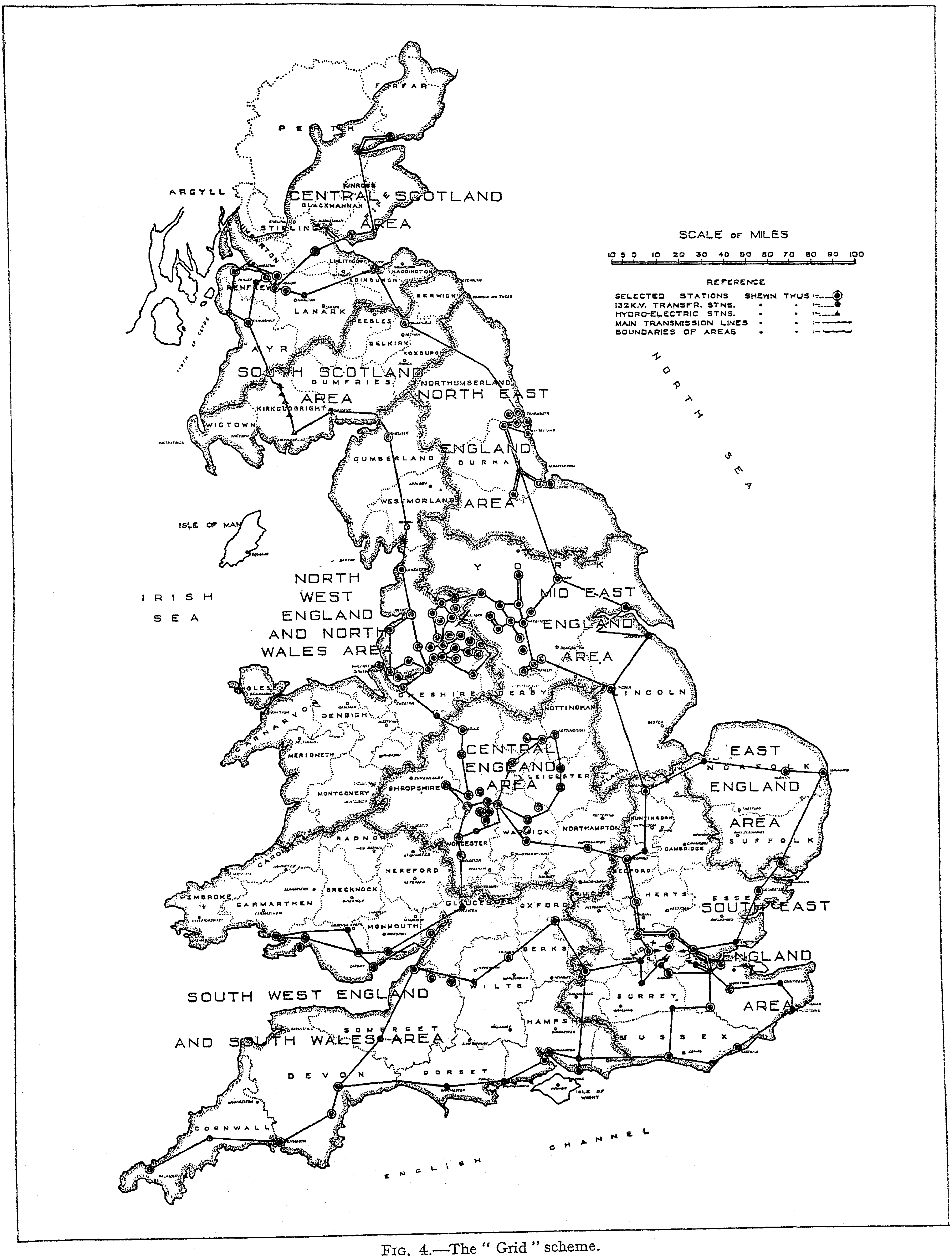

FIG. 4.—The "Grid" scheme.

private enterprise, but it is really surprising to find how many towns of quite a reasonable size were left entirely untouched and considerable areas completely neglected. This state of affairs is being rapidly remedied and, indeed, it is very necessary that it should be, otherwise it will be quite impossible for the country to get the full benefits of the grid system of the Central Electricity Board. Unfortunately, many people are under the impression that the great lines which they see going up will immediately bring a supply of current to the houses which they closely approach, and bitter disappointment is created when they are told that nothing of the sort will happen. It is indeed, I think, a little unfortunate that the name "grid" has become attached to this system. It bears little resemblance to a grid when we see it on the map (Fig. 4), and I think that St. Lawrence, who suffered martyrdom, it is said, on a grid-iron, would have found it very difficult to accommodate his frame on a grid of this description. Incidentally, if the Central Electricity Board are in need of a patron saint, I might venture to suggest St. Lawrence as suitable.

Were it not for the fact that the name might be confused with a method of London transport, I should very much like to have heard the grid termed the "national 'bus," for so, indeed, it is. It is nothing more than a system of busbars interconnecting various stations. It might very fairly be described as the arterial system of the electricity supply in this country, not forgetting, of course, that the veins are required to bring back the used blood which has been carried from the heart by the arteries; but the venous and arterial system of a body, even fitted, as is the grid, with more hearts than one, would be of little use—in fact, of no use at all—to the body in general, were it not for the little system of subsidiary veins or arteries which carry the blood to all parts of the body—in fact to the capillary system, and it is this capillary system, or part of it, about which I wish to say a few words. I have endeavoured to discover from some medical friends the length ratio between the capillary system of the body and the arteries and veins, but it appears that this figure is not known. It is, however, a very large one and the point I want to make is that the electrical capillary system of the country must be many times that of the length of the main grid lines if we are to get the full benefits that this system will ultimately provide.

I have been at some pains to obtain particulars of the larger areas which have been, and are, in process of development. These particulars are not as complete as I should like, and, indeed, it is very difficult to get them all on precisely the same footing, but they do indicate how rapidly this process of electrifying the country is going on and how long this work has been proceeding. I had originally intended to indicate on a map the network of mains of various undertakers and to compare them with the grid system, showing the relation between the capillary and arterial systems, but, on taking a "trial run" on the two territories in which I am particularly interested, I found that this would be an impossible task, as no map could be prepared, even if I had time to do so, which would show in sufficient detail the ramifications. I have, however, prepared from existing maps a plan showing the two areas I have mentioned, with the whole of their feeder mains, i.e. everything with the exception of the distributor mains, and I have also indicated the points at which tappings are made, on the same basis as I have explained already in Part 2 of this Address. On the same map this figure (Fig. 5) is superimposed on the grid system, and these two areas are together fairly typical of the country places. The part near London is semi-urban as it approaches the town, and is very well developed, while the northern part of the North Metropolitan Co.'s territory is almost entirely rural, and the Bedfordshire, Cambridgeshire and Huntingdonshire Co.'s area is largely fen country with a few large towns, but, even so, it will be seen how difficult it is to get a clear idea of the feeder system. It will suffice, however, to say that the total mileage of feeder mains is 965 and the total number of supply points as defined above is 482, compared with 100 miles and 6 breakdown points in the case of the grid system adjoining that territory.

Finally I have produced a map (Fig. 6)* which indicates, in addition to the power companies' territories already shown, the various undertakings that are filling the gaps, and although, as I say, this is not complete, it will indicate how very well covered the country now is, and I think little remains to be pre-empted. I am not saying that the mere fact that powers have been granted for electrification is any necessary criterion, but it is a very great advance on the condition of affairs only a few years ago, when very large tracts of the country with large populous centres had no possible supply at all.

Table 3 (which I cannot expect you to digest) gives in a tabular form the same sort of particulars as I have given for the power companies, except that, in this case, I have given only the dates of the Acts or Orders, the square mileage and the mileage of feeder mains and distribution centres. These figures may be added directly to those of the power companies, and this will give a very fair idea of the extent to which electricity has penetrated the country as distinct from the larger towns, which I have not dealt with specifically. In the areas of the older power companies the work had naturally to be done by overhead lines, and I imagine that electrical mains are now so common a sight that people take no more notice of them than they do of the telegraph and telephone erections; but it is very interesting to note on one's travels the progress of electricity, which is made so much more evident when overhead wires are used and one can see these lines, generally unostentatiously, running over various parts of the country. I have seen them round the Broads district, where Norwich and Yarmouth are operating; in the fen country, in the Isle of Ely, where the Bedfordshire Co. have powers; under the foot-hills of the Mendips by the North Somerset Power Co.; and in the country districts of Essex by the East Anglian and the County of London companies, to mention but a few of the places where this work is rapidly being carried out.

There is just one thing I might say in regard to this part of my Address, and that is that the connection between town and country is now so close that many

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* It must be emphasized that this map and Table 3 are intended to deal with rural supplies only, as far as they can be separated. Suburban areas are excluded, also some rural areas of small size and a few others where the rural work could not be separated from the town supply.

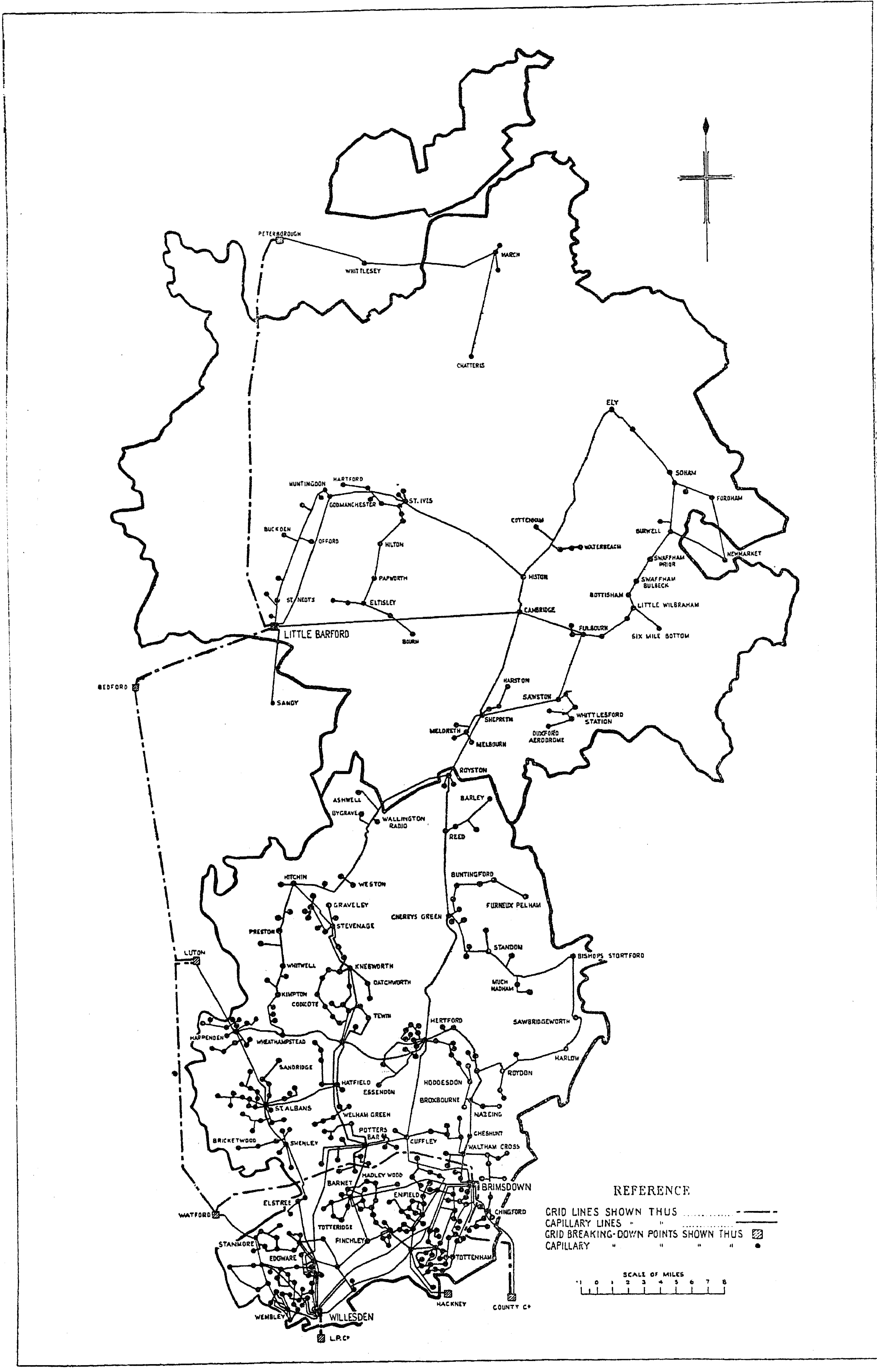

Fig. 5.—" Grid " lines and capillary system in area north of London.

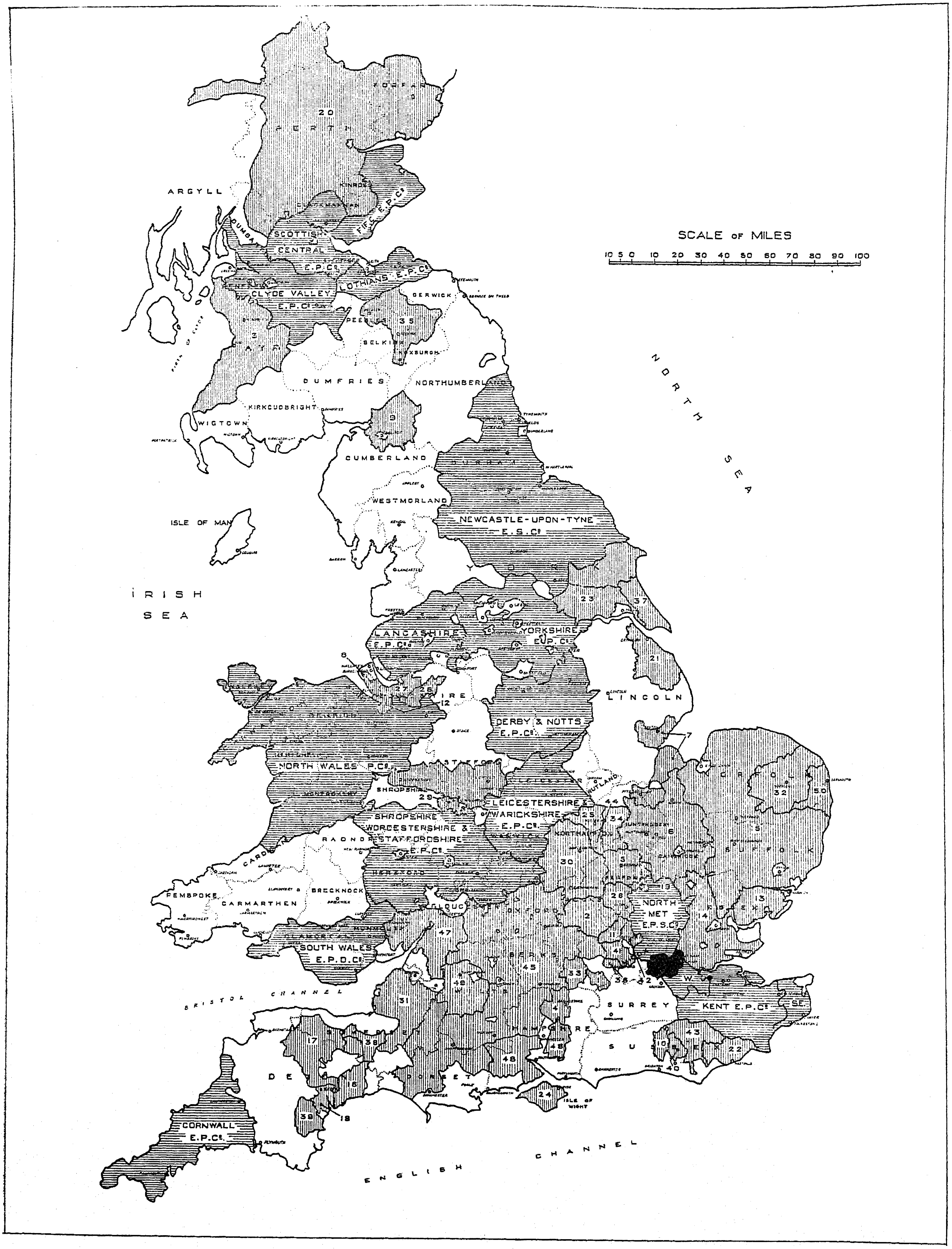

FIG. 6.—Electricity supply in rural areas.

TABLE 3.

Rural Areas.

Map reference	Undertaking	Date of Act or Acts	Total territory	Length of high-tension mains	Number of transformer centres	Units sold, 1930
			sq. miles	miles		
1	Ascot District Gas and Electricity Co. ..	1906	74	30	14	1 226 513
2	Aylesbury Corporation	1925, 1929	225	125	98	4 795 762
3	Ayrshire Electricity Board	1914–1924	1 130	300	296	43 315 896
4	Basingstoke Corporation	1927	141	24	18	120 020
5	Bedford Corporation	1924, 1926	196	216	182	9 908 638
6	Beds., Cambs. and Hunts. Electricity Co. ..	1925	1 185	175	61	10 667 354
7	Boston and District E.S. Co.	1926, 1928	216	39	30	180 237
8	Birkenhead Corporation	1900–1925	58	31	45	5 763 200
9	Carlisle Corporation	1911, 1930	392	40	22	1 038 747
10	Central Sussex Electricity, Ltd.	1922–1929	96	24	14	160 107
11	Chesham E.L. and Power Co.	1909, 1928	77	59	63	1 350 000
12	Chester Corporation	1923, 1927	138	66	51	2 061 154
13	Colchester Corporation	1928	260	72	49	815 000
14	County of London E.S. Co.	1905–1927	1 663	313	251	56 178 619
15	East Anglian E.S. Co.	1926, 1927	2 700	100	40	3 954 529
16	East Devon Electricity Co.	1929, 1930	190	40	24	898 485
17	Exe Valley Electricity Co.	1926–1929	502	23	9	241 956
18	Exeter Corporation	1925, 1931	24	17	16	364 056
19	First Garden City, Ltd.	1924, 1925	32	20	14	5 831 677
20	Grampian E.S. Co.	1922, 1930	5 000	247	63	7 934 483
21	Grimsby Corporation	1907, 1927	316	30	15	1 013 403
22	Hastings Corporation	1927	152	58	52	1 173 815
23	Hull Corporation	1914–1929	147	45	32	21 342 230
24	Isle of Wight E.L. and Power Co.	1897–1926	150	60	32	2 457 146
25	Kettering U.D.C.	1923, 1931	145	38	42	2 835 115
26	Luton Corporation	1924, 1927	192	52	26	11 602 607
27	Mersey Power Co.	1910–1929	78	90	58	35 204 122
28	Mid-Cheshire E.S. Co.	1897, 1924	120	65	173	1 880 000
29	Midland Electric Corporation	1898, 1926	42	34	45	2 634 100
30	Northampton E.L. and Power Co.	1904–1928	788	313	142	21 247 615
31	North Somerset E.S. Co.	1910–1929	600	211	114	8 135 948
32	Norwich Corporation	1926, 1930	700	175	130	1 500 000
33	Reading E.S. Co.	1910, 1923	90	60	39	1 580 000
34	Rushden and District E.S. Co.	1912–1925	168	38	28	3 639 105
35	Scottish Southern E.S. Co.	1914, 1926	426	77	46	5 908 588
36	Slough and Datchet E.S. Co.	1902–1926	37	43	70	2 042 895
37	South-East Yorkshire Light and Power Co.	1929, 1930	200	35	26	210 264
38	Taunton Corporation	1925	49	27	67	383 289
39	Torquay Corporation	1922–1930	182	80	52	4 857 237
40	Uckfield Gas and Electricity Co.	1925	70	29	9	2 960
41	Uxbridge E.S. Co.	1900–1906	43	80	257	3 719 899
42	Watford Corporation	1913–1922	39	58	118	5 338 915
43	Weald E.S. Co.	1923–1930	480	132	126	2 043 650
44	Wellingborough E.S. Co.	1900–1923	48	6	15	2 057 767
45	Wessex Electricity Co.	1927, 1928	4 600	285	136	17 251 351
46	West Cornwall E.S. Co.	1928	550	—	52	472 105
47	West Gloucester Power Co.	1924–1928	679	155	105	23 767 298
48	West Hampshire Electricity Co.	1924–1930	475	36	23	651 672
49	West Wilts Electricity Co.	1924, 1925	330	67	64	9 792 865
50	Yarmouth Corporation	1927, 1930	198	65	23	324 016
	Total	—	26 393	4 405	3 477	351 876 510

dwellers in the latter are well aware of the low prices of electricity which are charged in many of the towns, and they appear to consider that the fact that the price of electricity in the country is considerably higher than in the towns is an anomaly and a grievance. It cannot, however, be too strongly pointed out that the cost of supplying electricity in the rural areas depends a great deal more on the density of the population than on anything else—in other words, on the revenue per mile of main—and that even if the current were supplied for nothing, the prices for lighting, at any rate, would certainly be higher than they are in the towns. Once this point is appreciated, matters fall into their true proportion and it is recognized that the only possible way of reducing prices in the country areas is by a very much larger use of the facilities afforded, and it is on these lines that all enterprising authorities are now working.

CONCLUSION.

The electricity supply industry has been for a long time the plaything of the legislator, and the result has, on the whole, been unfortunate. It is suggested that the time has come when the legislator might usefully occupy his mind with other matters and leave the electricity supply industry alone to work out its own salvation. Wider areas of distribution, including artificial boundaries, may be desirable in some cases, although, personally, I should feel inclined, for practical reasons, to limit the size of such areas. Authorities are, however, now available for dealing with any such situation, and, in considering any future readjustment, the records of the present undertakings should be carefully scrutinized. The solution is such a simple one that one almost hesitates to mention it; it is that those concerns—whether they be run by public or private enterprise—which have, by their records, shown their ability to handle large areas and which have of necessity accumulated valuable experience and a trained and experienced staff, should be entrusted with wider powers. The process which is too often adopted at the present time bears a close resemblance to that of the small child who anxiously digs up his garden from time to time to see how the seeds are growing. The seeds of electricity supply are firmly and properly planted and can safely be left to fructify and increase if they are allowed to germinate naturally.

WIRELESS SECTION: CHAIRMAN'S ADDRESS

By Colonel A. S. Angwin, D.S.O., M.C., B.Sc.(Eng.), Member.

(*Address delivered 4th November*, 1931.)

Foreword.

I must in the first instance express to the members of the Wireless Section my appreciation of the honour which they have done me by selecting me as their Chairman for this session.

The active interest taken in the Section and the high standard reached in the papers presented have established its prestige and representative character in dealing with the specialized practice of those branches of electrical engineering which come particularly within the scope of the Wireless Section. The realization of this renders me the more conscious of the honour you have done me.

The membership of the Section has increased by 10 per cent during the past year. Doubtless some of this increase has resulted from the extension of the activities of the Section to include the electrical recording and reproduction of sound. Some of the papers to be read this session should particularly appeal to those members interested in these subjects.

I do not intend to put before you this evening a general review of the field of radio but shall confine myself mainly to the subject of frequency measurement and control.

Importance of Frequency Stability.

In the earlier development of wireless the predominant difficulty in establishing communication was the transmission of a signal of sufficient strength to be discriminated from the general level of noise, atmospherics, etc., emanating from other sources. Whilst the necessity of obtaining the requisite high ratio of signal to atmospheric noise-level is still an essential condition in radio communication, the invention and development of the thermionic valve and the utilization of improved types of antennæ and selective circuits have removed or reduced many of the difficulties. The development and extension of the many types of wireless services, particularly in the short-wave ranges, has, however, brought increasing difficulties in avoiding mutual interference between radio services not widely separated in frequency.

The medium by which radio communications are conveyed is universal, and however circumscribed in direction and limited in range the requirements for each individual transmitter may be, the possibility exists of propagation to and consequent interference with the receiving terminals of other radio channels. It is in regard to this particular aspect of radio that, from its earliest application to the art of communication, the necessity has arisen for international agreement and regulation to govern its employment.

The first important step in the direction of restricting interference was the allocation of specific bands of frequencies to the different categories of services, i.e. mobile, fixed, broadcasting, etc. The impossibility of any partition of frequencies between nations has long been realized and the problem is still left of meeting universal requirements for each category of service within its frequency allocations, whilst the demands for new channels are ever increasing. The logical development has been the closing-in of the frequency separation between channels, and the trend of international agreements and regulations is towards ensuring that the practice of the art shall be such that the smallest possible width of frequencies shall be employed for any channel of communication, having regard to the type of transmission involved, i.e. telephony, telegraphy, etc., and to the category of service, i.e. mobile, fixed, etc.

The total width of the frequency channel required for any communication comprises the actual modulation side-bands together with an allowance for the variation in the frequency of the transmission due to the imperfection of the frequency control. This allowance is known as the tolerance. The relative importance of these factors varies with the wavelength. On long waves the modulation band dominates; on the shorter wavelengths, however, the tolerance at present practicable is of the same order as or even greater than the modulation. In consequence, on short waves the greater economy in channel width can be effected by improvements in the frequency stability of transmitters.

The Comité Consultatif International Technique des Communications Radioélectriques (C.C.I.R.) have formulated recommendations and proposals on the questions of tolerances permissible on the nominal wavelength of a radio transmitter; the reduction of non-essential emissions; the band width of frequency for different types of transmission, etc. The consideration of these recommendations and the possible adoption of regulations based on them to endeavour to meet the demands for new channels in the ether will doubtless be among the most important problems to be discussed at the approaching International Radio-Telegraph Conference. I propose in this address to give some details of the work which the Post Office has done, (*a*) in setting up machinery in pursuance of its statutory obligations as the licensing authority for wireless in this country, whereby the situation as regards frequency variation of existing stations can be observed and measured and interference troubles remedied, and (*b*) in developing its own transmitters so that their performance, as regards the band width occupied in the ether, shall be within any tolerance which may be laid down in International Conferences.

Extensive and precise observations over long periods are essential in order clearly to establish and classify the conditions in regard to the various types of transmitters as they exist at present. A station capable of carrying out such observations must have facilities for easy and rapid search over the complete ranges of frequencies in commercial use, must be able to take accurate measurements quickly and must be in a position to check its reference frequency against some reliable sub-standard. The Post Office has had observation stations in operation for some time taking measurements, not only on stations operating in this country, but verifying the frequencies of stations operating elsewhere which may be the cause of interference with reception in this country. It is from observations such as these that deductions can be made as to the limits which can be regarded as applicable in the present state of the art and the directions in which improvement is most necessary.

As a prelude to the discussion of the results of some of the observations made it is perhaps well to give a brief description of the equipment at the St. Albans (Colney Heath) station, which was established specifically for frequency measurement, and at the Radio Laboratory at Dollis Hill, in order to outline the procedure adopted for measurement and the steps taken to ensure accuracy in the results.

DOLLIS HILL FREQUENCY SUB-STANDARD.

The sub-standard of frequency used by the Post Office is an electrically-driven, temperature-controlled, elinvar tuning fork which is maintained in the Radio Laboratory at Dollis Hill.

The fork and its driving unit are contained within the inner compartment of a double oven, the temperature of the inner oven being controlled by a thermostat at 30° C. The temperature of the space between the ovens is also controlled by a thermostat, in this case to about 25° C.

The temperature coefficient of the fork is + 5 parts in 10^6 per degree C., whilst the actual temperature variation of the fork is estimated to be not greater than 0·01 deg. C. The change of frequency of the fork on account of temperature is thus within 5 parts in 10^8. The temperature, 30° C., of the inner oven is such that at a given atmospheric pressure the fork frequency is 1 000·000 cycles per second.

In order to obtain a comparison with unit time, amplified output from the tuning fork is used to drive a phonic motor equipped with a cam which makes a contact every second and operates one of the coils of a double-coiled siphon recorder registering on a tape. The other coil of the recorder is operated by the time signals from Greenwich Observatory, sent out at 10 00 G.M.T. and 18 00 G.M.T. from Rugby. By comparisons over this 8-hour period the total maximum error from all sources in making the time record is estimated not to exceed 0·58 part in 10^6.

The results of frequent tests made in co-operation with the National Physical Laboratory indicate that the order of accuracy as compared with the national standard is better than ± 1 part in 10^6.

Multivibrator equipment of the type developed by D. W. Dye was first installed at Dollis Hill for measurements of low- and medium-range frequencies, and by the addition of special controlled oscillators operating at frequencies up to the 300th harmonic of the tuning fork the method of measuring was extended to the medium-high and high radio frequencies.

This equipment has been described by F. E. Nancarrow.*

ST. ALBANS (COLNEY HEATH) FREQUENCY-MEASURING STATION.

In order to deal expeditiously with cases of interference, particularly those relating to high-speed telegraphy stations which are sometimes difficult to identify, it was decided to locate an observation and checking station close to and associated with the St. Albans receiving station, where an expert telegraph staff was available as well as a complete range of long-wave and short-wave receivers.

A site was selected in this vicinity at Colney Heath, which has peculiar advantages in being well removed from sources of local interference, at the same time being conveniently situated for telephone communication and easily accessible.

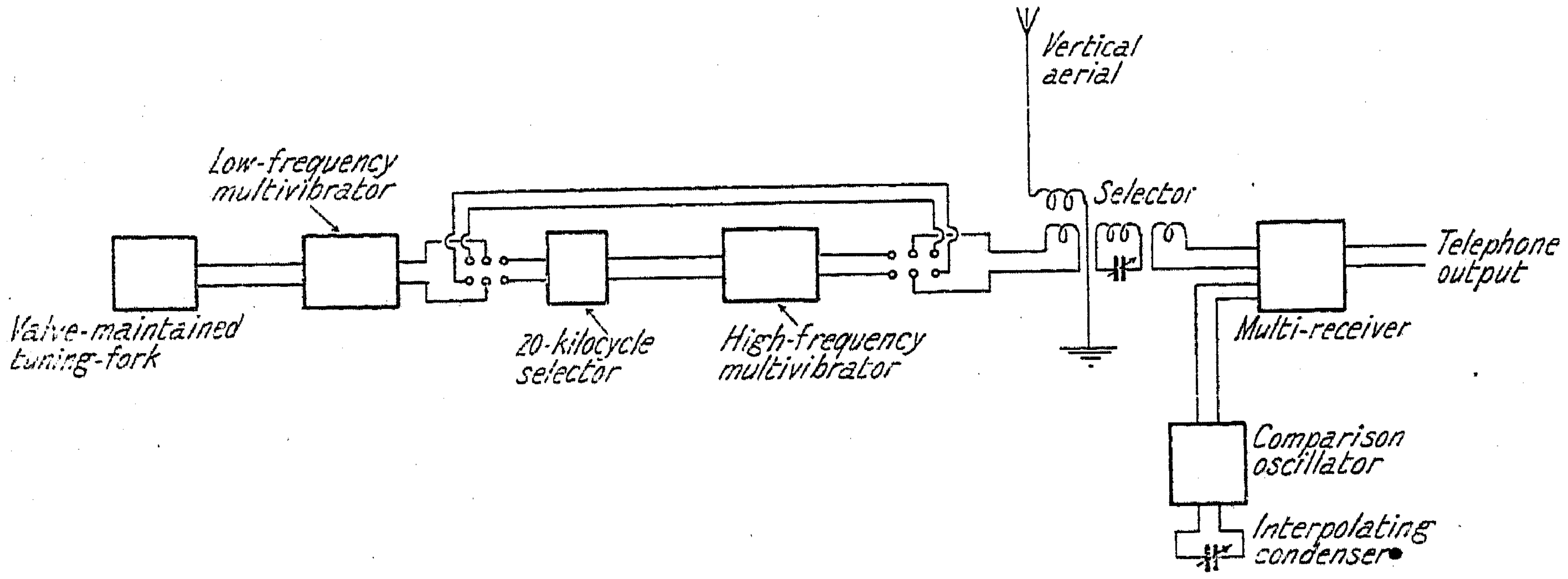

FIG. 1.—Schematic diagram of long-wave measuring apparatus.

The secondary frequency standard used at St. Albans is a valve-maintained tuning fork associated with a multivibrator equipment of similar type to that at Dollis Hill. This fork is not, however, temperature controlled, but, as described later, is frequently checked against the Dollis Hill standard fork.

The principles of the multivibrator as applied to low radio frequencies have been described by Dye.† Briefly the valve-maintained tuning fork, oscillating at a fre quency of 1 000 cycles per sec., controls precisely a multivibrator which has the same fundamental frequency and from which any harmonics between the 10th and 115th are selected, giving a range of 10 to 115 kilocycles per sec. at intervals of 1 000 cycles.

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* *Post Office Electrical Engineers' Journal*, 1931, vol. 24, p. 155.

† *Philosophical Transactions of the Royal Society*, A, 1924, vol. 224, p. 259.

To extend the range of the wavemeter above a frequency of 115 kilocycles per sec., beyond which the harmonics become difficult to identify, the 20th harmonic of this multivibrator is selected and amplified and in turn controls precisely a second multivibrator having a fundamental frequency of 20 kilocycles per sec. The 6th to the 72nd harmonics of this high-frequency multivibrator are selected, giving a frequency range of 120 to 1 440 kilocycles per sec. at intervals of 20 kilocycles.

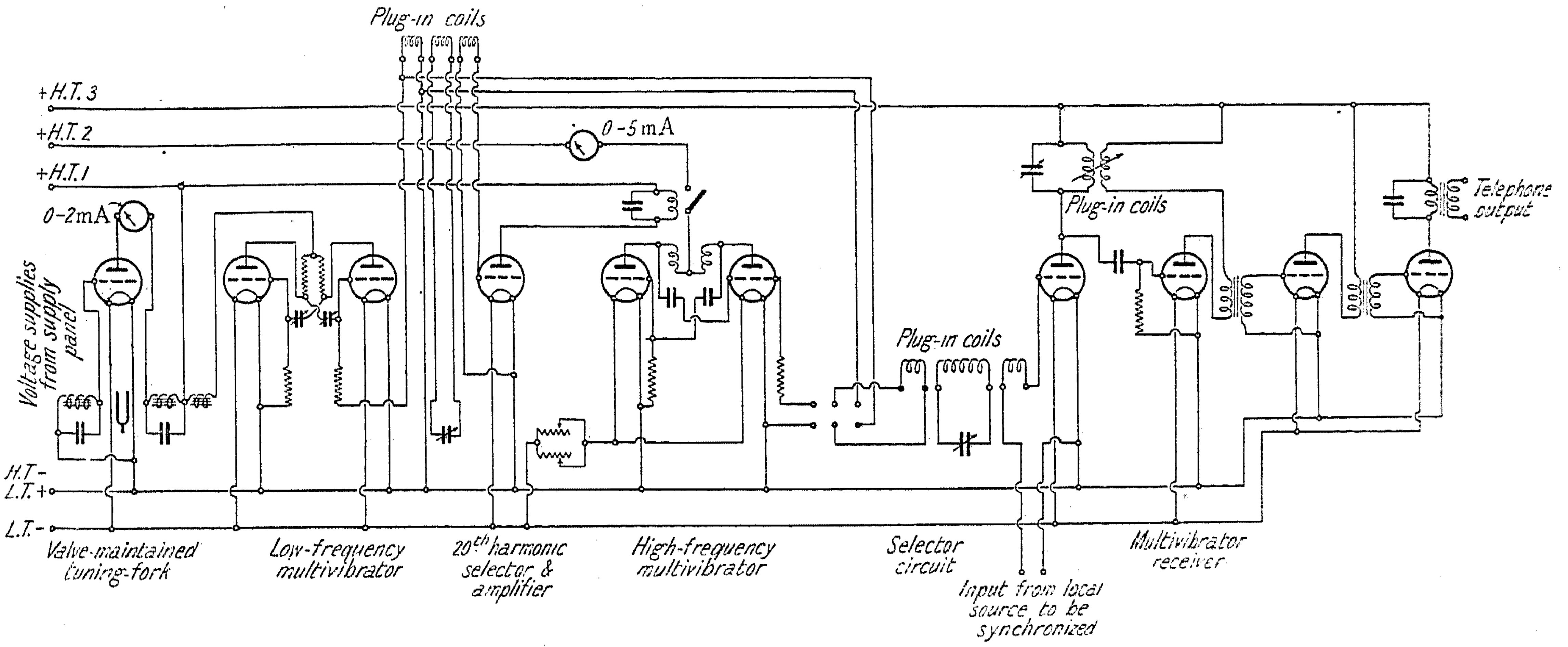
Plug-in coils
+H.T.3
+H.T.2
+H.T.1
0-5 mA
0-2mA
Voltage supplies from supply panel
H.T.-
L.T.+
L.T.-
Plug-in coils
Plug-in coils
Telephone output
Valve-maintained tuning-fork
Low-frequency multivibrator
20th harmonic selector & amplifier
High-frequency multivibrator
Selector circuit
Input from local source to be synchronized
Multivibrator receiver

FIG. 2.—Circuit diagram of multivibrator wavemeter.

Long-Wave Measurements 10–115 *kilocycles per sec.*

A schematic diagram of the measuring set as used for long-wave measurements is shown in Fig. 1, and the multivibrator and receiver in Fig. 2. The aerial circuit is loosely coupled to the selector circuit and the multivibrator receiver tuned to self-oscillation, so near to the frequency of the signal received from the station required to be measured as to give an audible note. The output of an oscillator, designated the comparison oscillator, which employs a special interpolating condenser in parallel with the normal tuned circuit condenser, is coupled to the receiver and its frequency is set by the interpolating condenser in sychronism with the incoming signal by the double-beat method. The circuit diagram of this oscillator, which is designed to maintain a high order of frequency constancy, is indicated in Fig. 3. From the calibration of the oscillator the approximate frequency of the oscillation is obtained and two adjacent harmonics of the multivibrator are then selected on either side of the frequency to be measured.

Each of the two harmonics in turn is selected and tuned on the receiver, which is now used in the non-oscillating condition. The comparison oscillator is synchronized with the selected harmonics by adjustment of the interpolating condenser, and its scale readings are observed. The frequency of the signal to be measured is then determined by interpolation from the three settings of the condenser. By the use of subsidiary harmonics and interference tones the interpolation interval may be reduced to less than 200 cycles.

The interpolating condenser is a standard laboratory air condenser of 0·0012 μF maximum capacitance, having a scale divided into 1 800 parts which can be accurately read to a fraction of these divisions.

Measurements in the Range 115–1 440 *kilocycles per sec.*

A similar method is used as for the long-wave range, with the exception that harmonics of the high-frequency multivibrator are employed. The frequency of the comparison oscillator is normally set by means of subsidiary harmonics to frequencies differing by 1 kilocycle, but narrower interpolation intervals may be obtained.

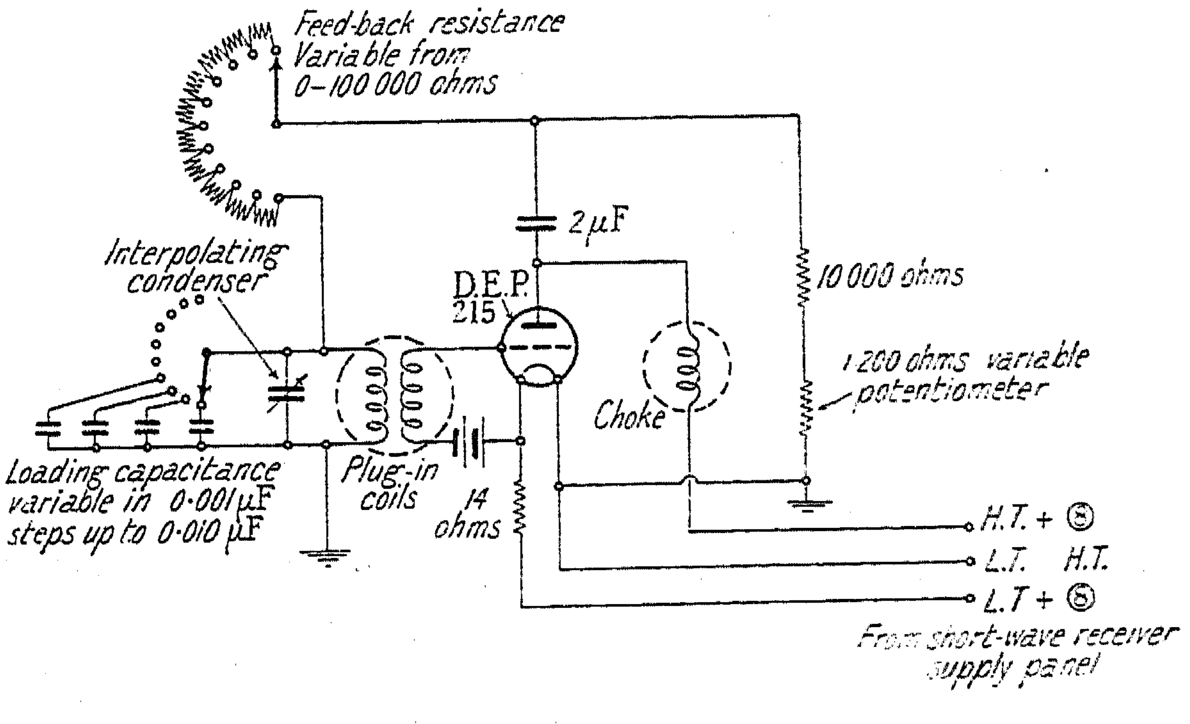
Feed-back resistance Variable from 0–100 000 ohms
2μF
Interpolating condenser
D.E.P. 215
10 000 ohms
1 200 ohms variable potentiometer
Choke
Loading capacitance variable in 0·001μF steps up to 0·010 μF
Plug-in coils
14 ohms
H.T. + ⑧
L.T. H.T.
L.T + ⑤
From short-wave receiver supply panel

FIG. 3.—Long-wave comparison oscillator.

Short-Wave Measurements—Frequency range 1 440–24 000 *kilocycles per sec.*

The special points which had to be considered in the design of the apparatus to cover this range of frequencies were to obtain sensitivity of the receiver comparable with that of the best short-wave receivers, and the facility for both quick and accurate measurements.

The receiver is of the super-heterodyne type, the intermediate frequency being fixed at 240 kilocycles per sec., and it is highly selective.

Fig. 4 shows a schematic diagram of the system employed to extend the harmonic frequency range to cover these frequencies. The output of either the high-frequency or low-frequency multivibrator can be switched to the input of an amplifier known as the synchronizing amplifier. The harmonic output of this amplifier is coupled to an oscillator known as the "reference oscillator" in such a way that as the fundamental frequency of the latter is varied its frequency is pulled into step and synchronized by each harmonic in turn. It is thus possible to synchronize the reference oscillator with a range of frequencies which are integral multiples of the tuning-fork frequency. The output of this oscillator is arranged to be rich in harmonics, and these harmonics, which are exact multiples of the tuning-fork frequency, are employed as the reference frequencies for short-wave measurements.

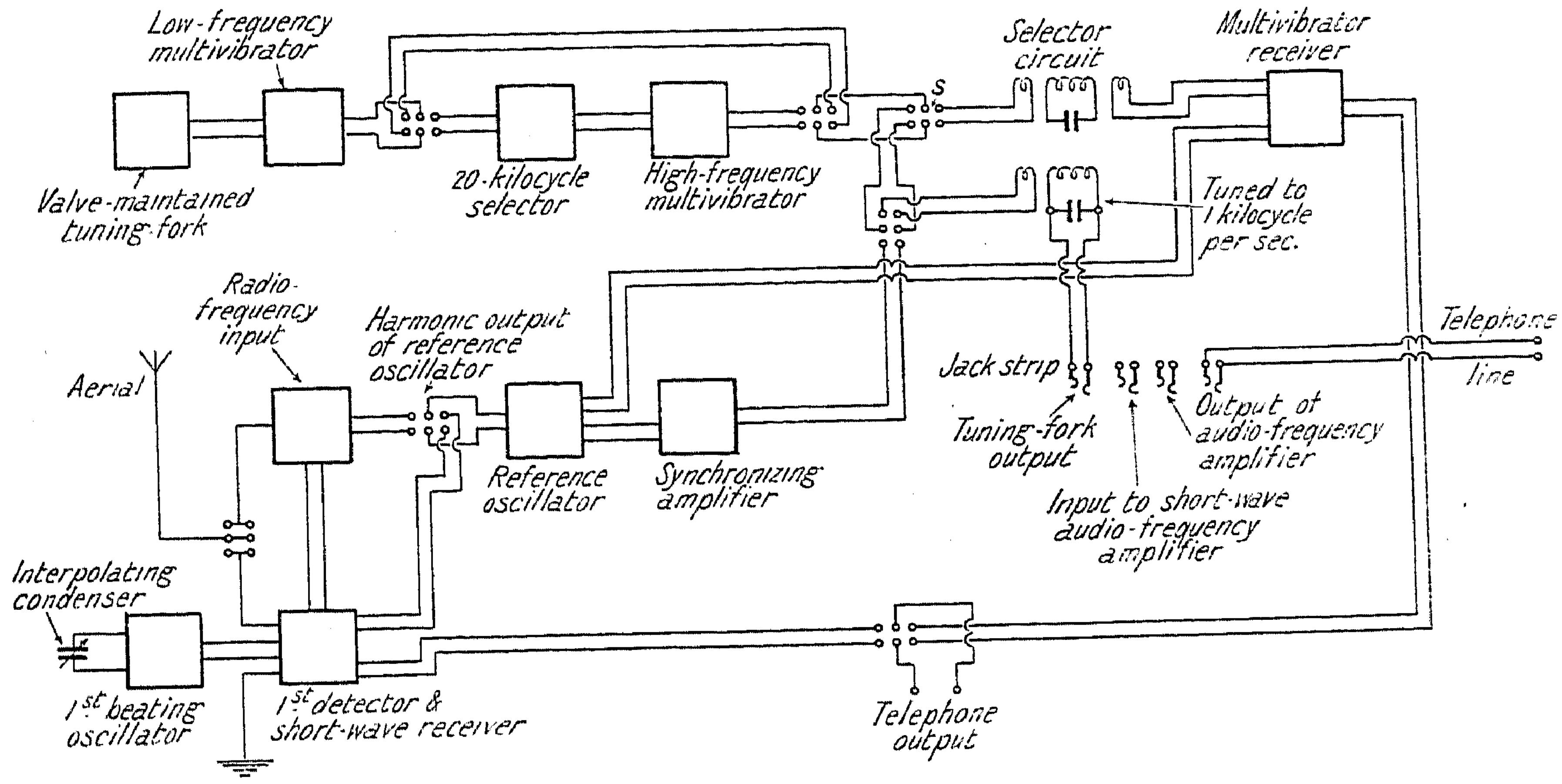
Low-frequency multivibrator
Valve-maintained tuning-fork
20-kilocycle selector
High-frequency multivibrator
S
Selector circuit
Multivibrator receiver
Tuned to 1 kilocycle per sec.
Telephone line
Radio-frequency input
Harmonic output of reference oscillator
Aerial
Reference oscillator
Synchronizing amplifier
Jack strip
Tuning-fork output
Output of audio-frequency amplifier
Input to short-wave audio-frequency amplifier
Interpolating condenser
1st beating oscillator
1st detector & short-wave receiver
Telephone output

FIG. 4.—Schematic diagram of apparatus to extend harmonic range of multivibrator wavemeter.

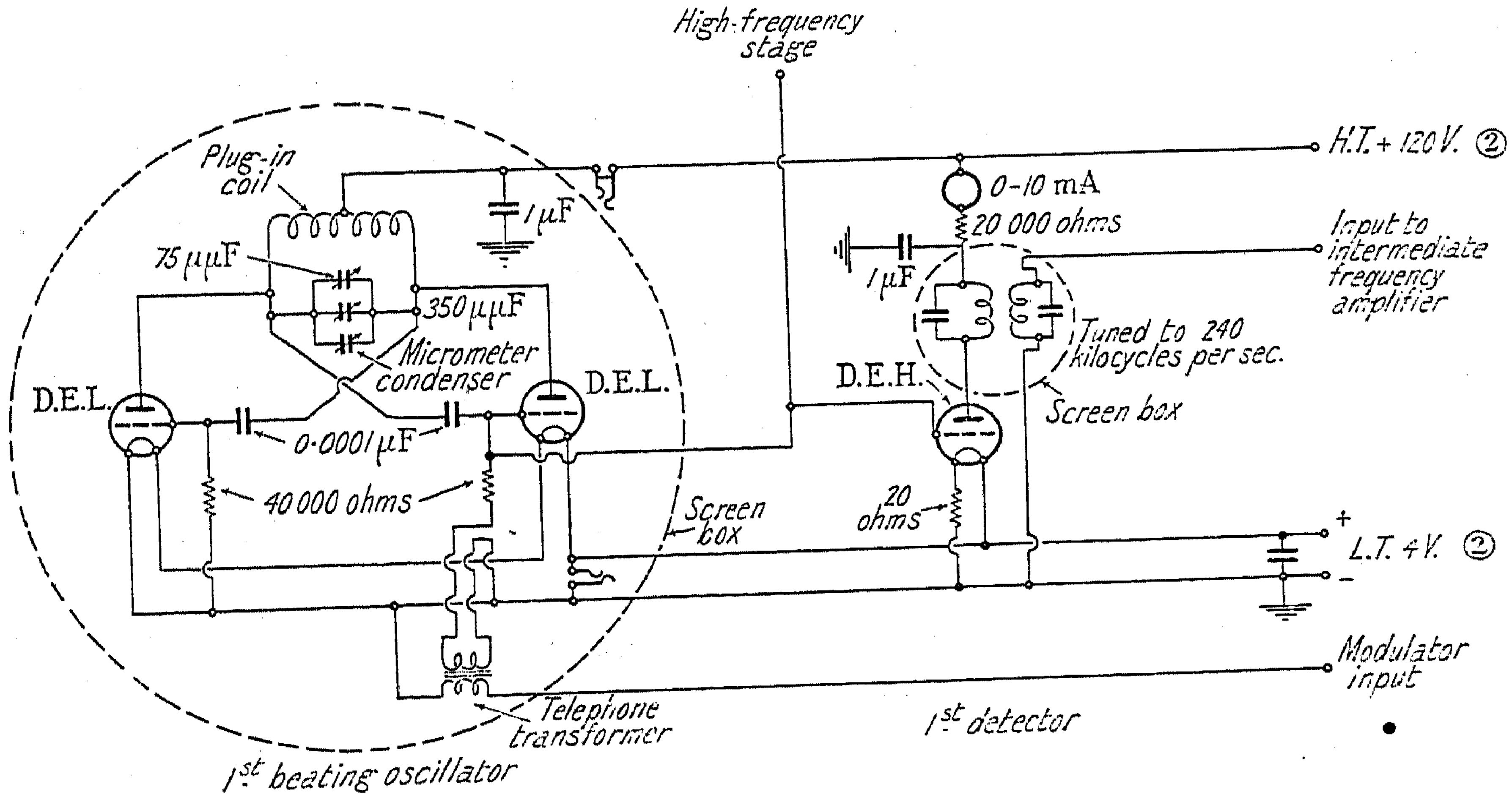

FIG. 5.—First detector and first beating oscillator.

Interpolation intervals can thus be obtained between successive harmonics the frequency of which (in kilocycles) is equal to the order of the reference oscillator harmonic employed. If a higher order of accuracy is required it is practicable to obtain interpolation frequencies separated by the fundamental frequency of the tuning fork.

The synchronization of the oscillator with the signal and the harmonics on either side by means of an interpolating condenser is effected similarly to that adopted for long-wave measurements.

In practice it is found more convenient to use the 1st beating oscillator to serve the additional purpose of comparison oscillator. This is effected by fitting in parallel with the normal tuned circuit condenser a special interpolating condenser having a linear displacement/capacitance curve.

The circuit arrangements of the 1st beating oscillator with the interpolating condenser is shown in Fig. 5. This condenser has some special features to meet the requirements, which are:—

(a) Maximum variable capacitance of 10 $\mu\mu$F with a linear relationship between capacitance and scale reading.

(b) Absence of hand-capacitance effects.

(c) Vernier adjustment to enable the oscillator to be precisely set to all frequencies in the working range.

It is of the concentric-cylinder type and comprises a brass plunger sliding into a slightly larger-diameter cylinder mounted on ebonite. The hollow cylinder and the plunger are the fixed and moving electrodes respectively. Backlash is avoided by mounting the condenser vertically, contact between the steel tip on the plunger and the ball bearing on the head of the micrometer screw being maintained by gravity.

The lengths of the plunger and cylinder and the working limits of the movement of the plunger are such that end-effect errors are negligible. The micrometer vernier can be accurately read to within ± 0·00005 in., which represents a capacitance change of approximately 0·0006 $\mu\mu$F.

Some details of the design of condensers of this type have been described by Mr. A. J. Gill.* The multivibrator equipment is mounted on a bench. The remainder is of standard panel and rack construction divided into a number of separate units each mounted on aluminium panels and enclosed and screened by copper boxes fitted over the back of the panel. The racks are mounted on a concrete pier and the floor is separated from the pier by about a ¼-in. space to avoid any vibration from the floor affecting the apparatus. To minimize temperature variation in the measuring room double doors and walls are employed and the room is heated by a hot-water circulating system. Both the long- and short-wave aerial systems are suspended from the cross-arms of an 80-ft. vertical pole.

As previously stated, the multivibrator fork at St. Albans is not temperature-controlled. The latest calibration gives it a temperature coefficient of − 8 parts in 10^6 per degree C. rise in temperature. All readings taken at the station are corrected for temperature.

COMPARISONS BETWEEN THE ST. ALBANS STATION AND DOLLIS HILL SUB-STANDARD.

An arrangement has been brought into operation whereby the tuning fork at St. Albans can be readily calibrated without disturbance by comparison with the standard tuning fork at the Dollis Hill Radio Laboratories, use being made of an ordinary telephone connection between the two places. As this method may have useful applications elsewhere some details of the apparatus may be of interest.

The circuit arrangement is shown in Fig. 6. By means of the switch S the output from the multivibrator is changed over from its normal connection to the inducing coil and connected to the coil L. The latter coil is caused to be coupled to the circuit C, which has a fundamental frequency of 1 000 cycles per sec., and the resultant oscillation is amplified through the low-frequency amplifier of the short-wave receiver and thence passed to the line. Coupling the output of the multivibrator in this manner ensures that the load in the fork is unchanged from when working into the selector circuit of the multivibrator apparatus, and hence its frequency is unaltered.

At Dollis Hill the received signal is passed through one low-frequency amplifier (No. 1) and the output mixed with the output of another low-frequency amplifier (No. 2) which is fed from the amplifier associated with the standard tuning fork. Steps are taken to adjust the gain of these amplifiers so that their outputs are equal, and the mixed signals are then rectified. The resultant pulses, which have a frequency corresponding to the beat frequency of the admixed signals, are caused to operate a telegraph relay, the local circuit of which is connected to one of the coils of a double siphon recorder, thus giving a record on the tape.

The second coil of the recorder is connected to the seconds contact on a phonic motor which is driven by and runs in synchronism with the standard fork, as indicated in the figure. The frequency of the standard fork is such that the "seconds" intervals as marked on the tape are never different from unit seconds by more than ± 3 parts in 10^6 and, as will be seen later, the error resulting from this difference is infinitesimally small.

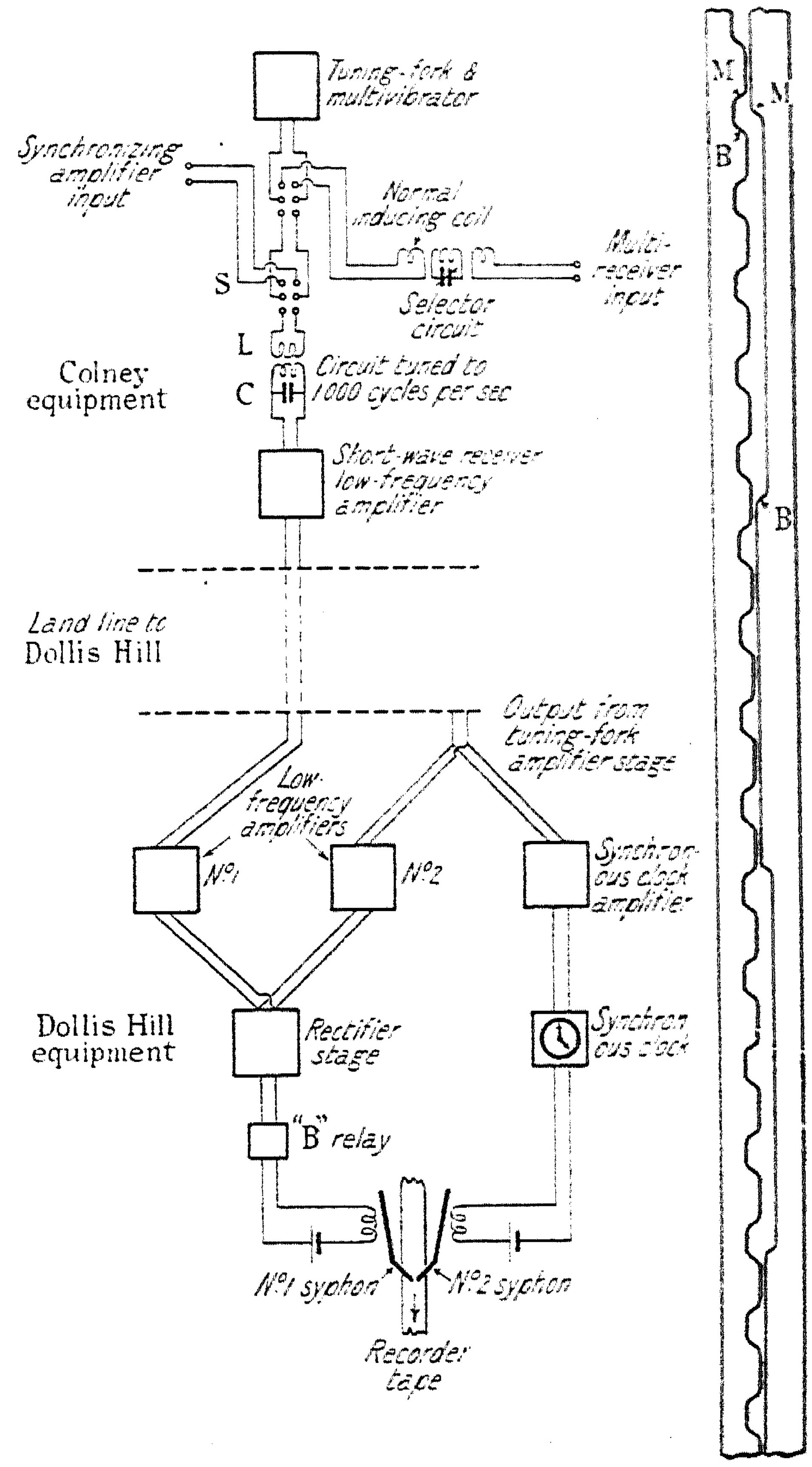

FIG. 6.—Schematic diagram of apparatus required to compare the frequencies of the Colney Heath and Dollis Hill tuning forks.

The fork at St. Albans is known to have a frequency depending on the temperature between 1 000·050 and 1 000·100 cycles per sec., and hence the beating rate will be between 5 and 10 beats per 100 seconds. Thus if the measurement is made over 100 secs. and this interval is known to ± 0·1 sec. the comparison is obtainable to an accuracy within ± 5 and ± 10 parts in 10^8, depending on the actual frequency of the fork.

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* *Journal I.E.E.*, 1931, vol. 69, p. 520.

The temperature of the fork is obtained by a thermometer fixed with its bulb in contact with the metal base to which the fork is clamped. For all normal temperature-changes the reading thus obtained is a very close approximation to the actual fork temperature.

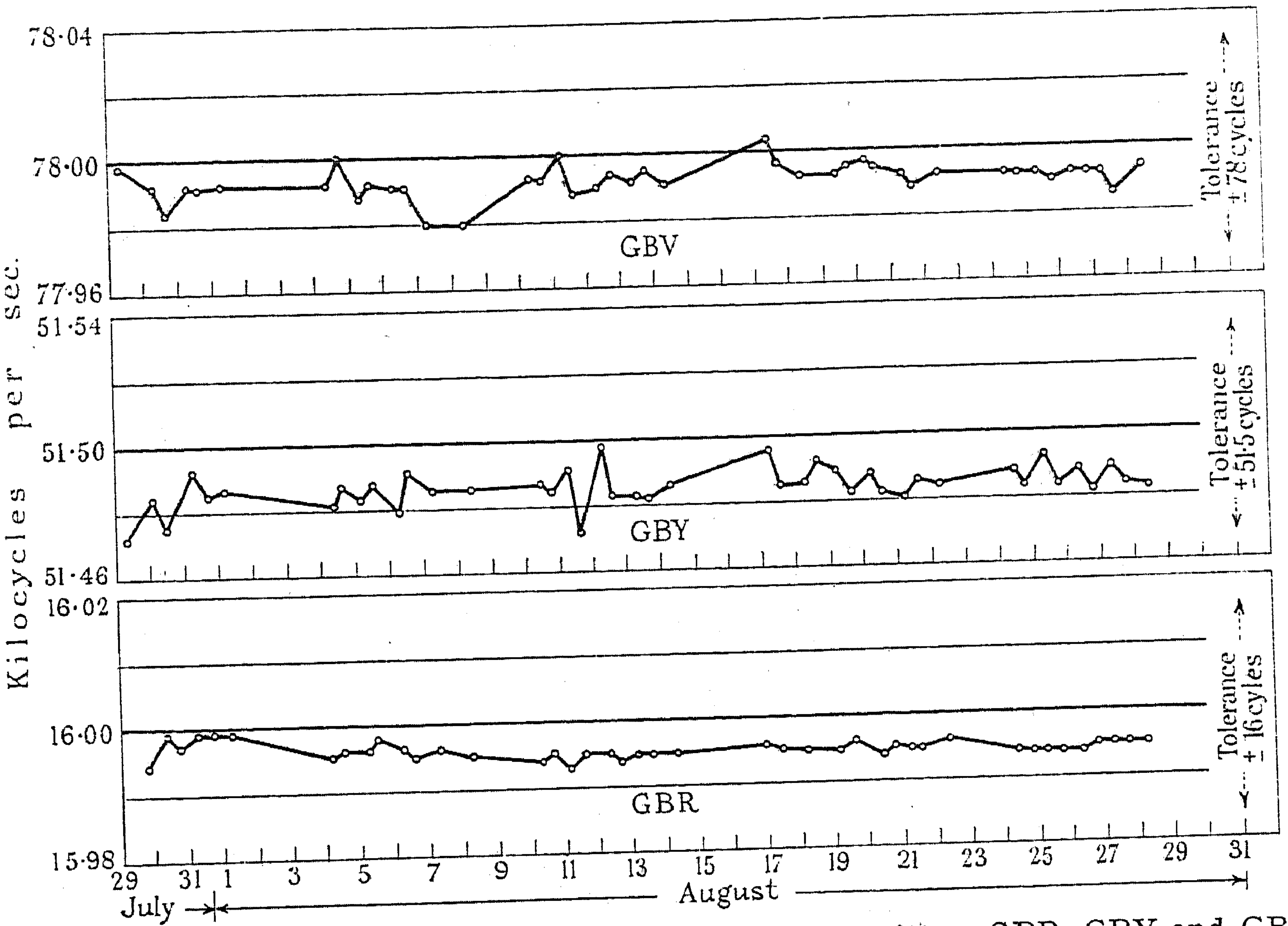

Fig. 7.—Frequency measurements on the tuning-fork controlled transmitters GBR, GBY and GBV (frequency allocations 16·0, 51·5 and 78·0 kilocycles per sec., respectively) carried out at Dollis Hill July–August, 1931.

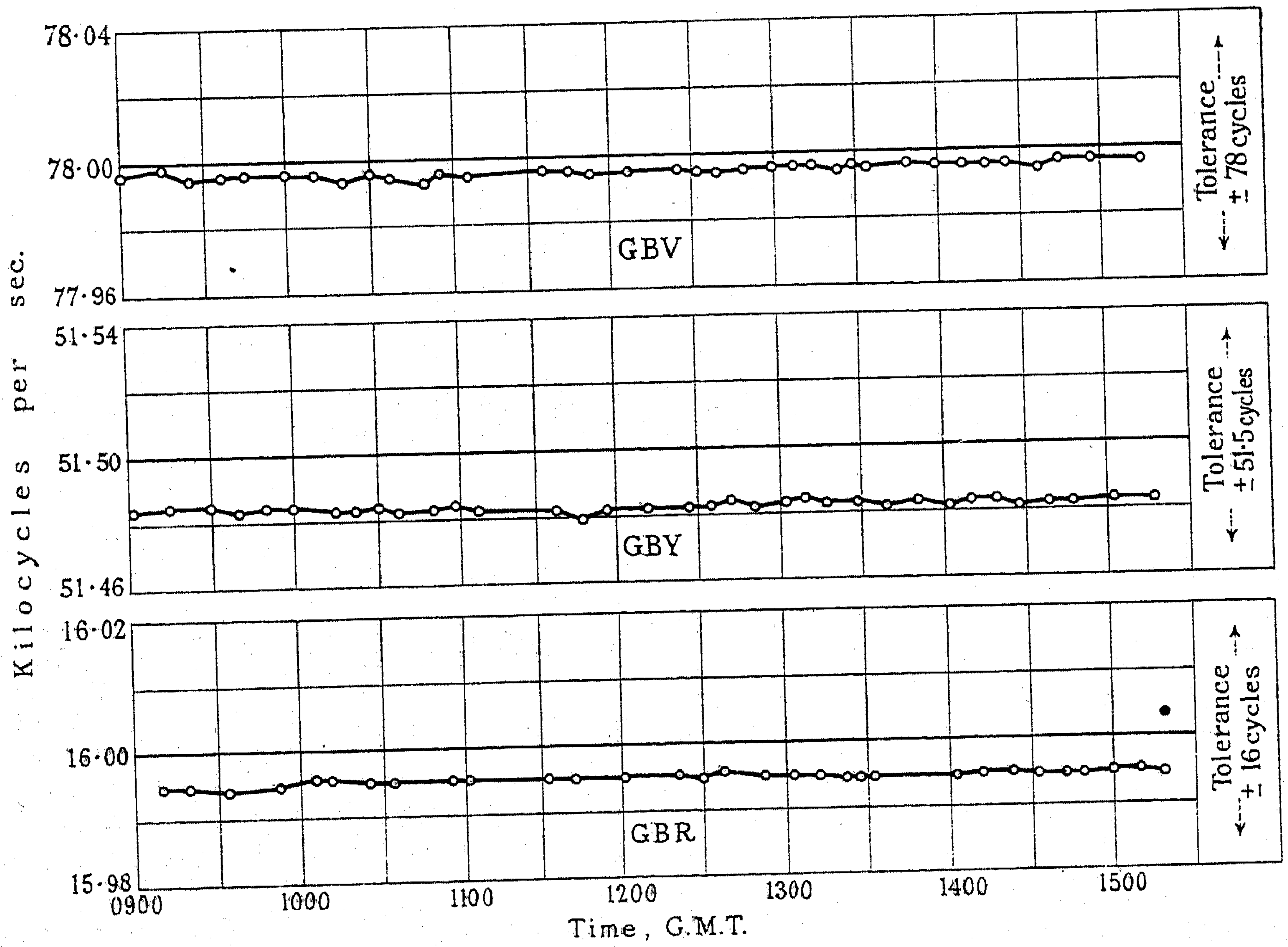

Fig. 8.—Frequency measurements on the tuning-fork controlled transmitters GBR, GBY and GBV (frequency allocations 16·0, 51·5 and 78·0 kilocycles per sec., respectively) carried out at Dollis Hill 1st September, 1931.

An example of the tape record obtained is shown on the right of the figure, the long dashes representing the beats and the short dashes the seconds record. The points M and B are "make" and "break" connections respectively.

The results of a number of measurements of the frequency of the St. Albans fork carried out by this method show that the maximum error to be expected by using the value of frequency given by the frequency/temperature chart used with the fork is 11 parts in 10^6, and that the average error is very much lower than this figure.

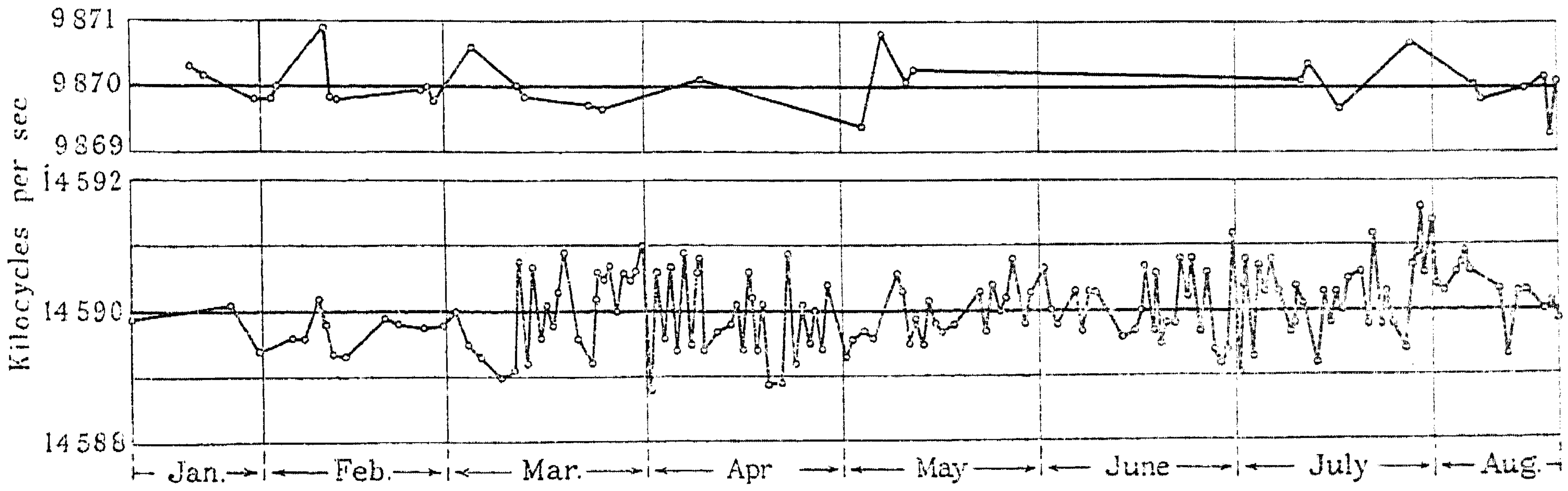

FIG. 9.—Frequency measurements on WMI (frequency allocations 9 870 and 14 590 kilocycles per sec.) carried out at Colney Heath 12th January–20th August, 1931.

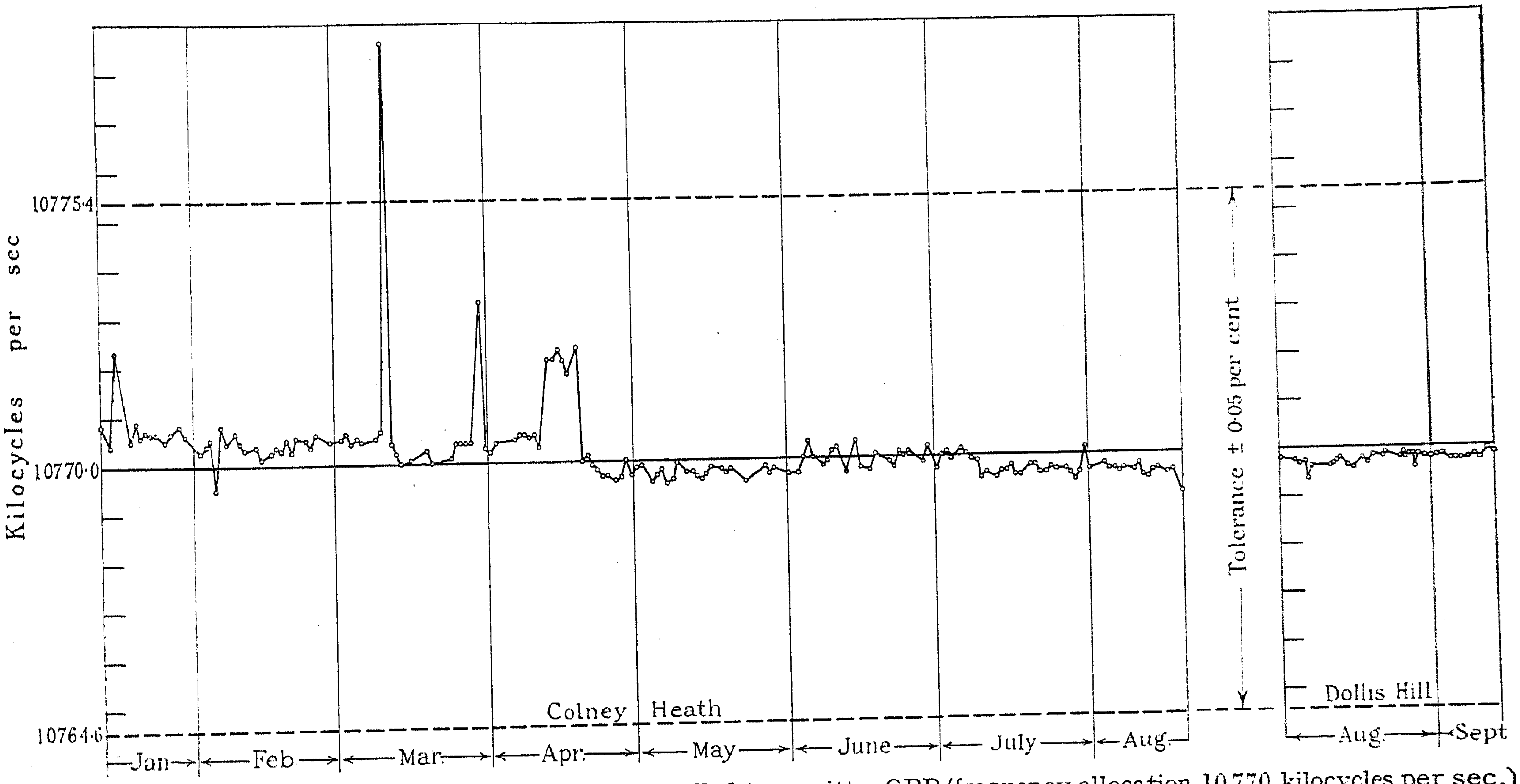

FIG. 10.—Frequency measurements on the crystal-controlled transmitter GBP (frequency allocation 10 770 kilocycles per sec.) carried out at Colney Heath and Dollis Hill.

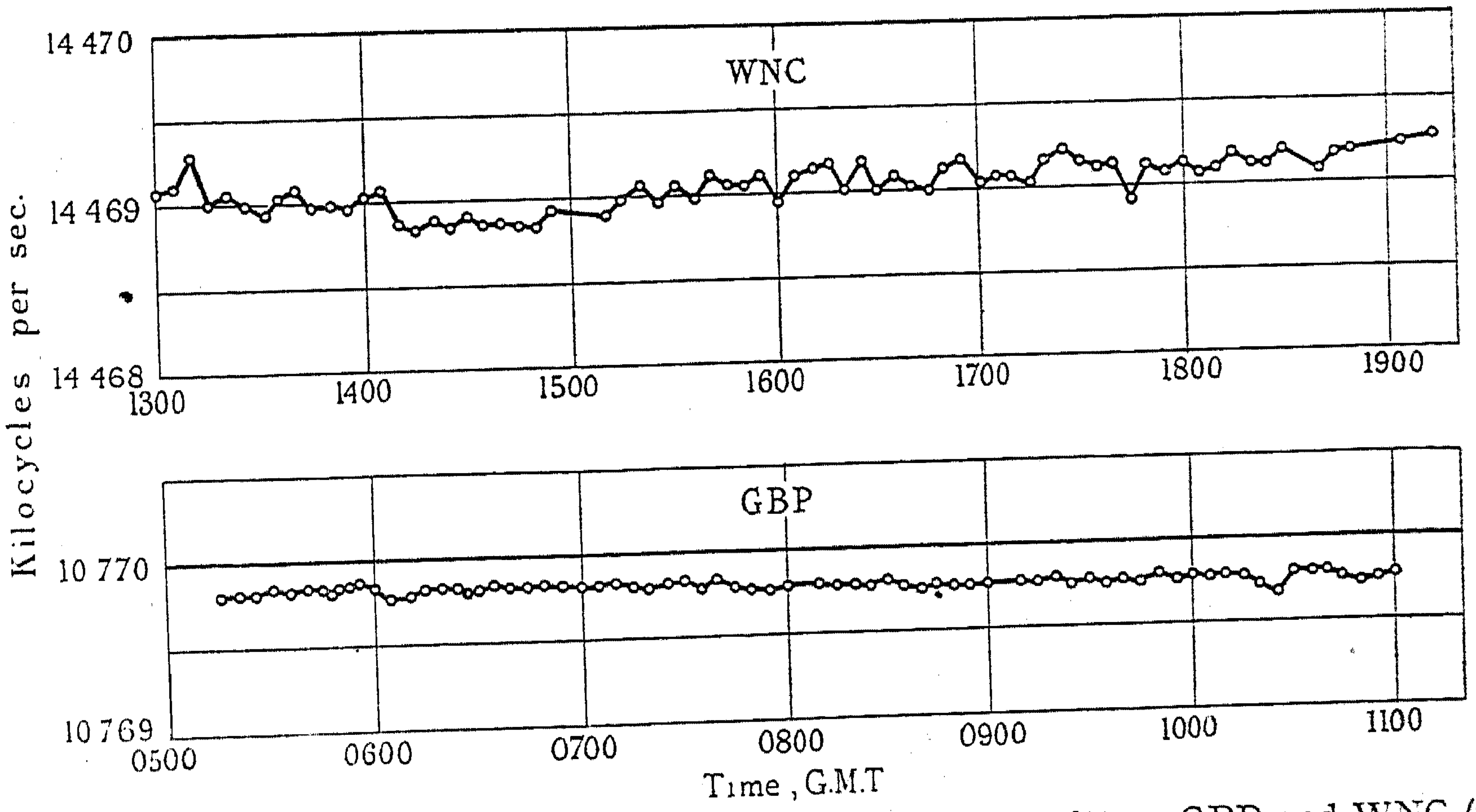

FIG. 11.—Frequency measurements on the crystal-controlled transmitters GBP and WNC (frequency allocations 10 770 and 14 470 kilocycles per sec., respectively) carried out at Dollis Hill.

Advantage has also been taken of special transmissions sent out by the National Physical Laboratory to check the accuracy of actual measurements at radio frequencies. As an example, measurements on a transmitter operating on 1 785 kilocycles per sec. carried out over a period of one hour showed an average of the St. Albans measurements of 14 cycles above the Dollis Hill figures, a difference of + 8 parts in 10^6. The Dollis Hill measurements agreed with those of the N.P.L. to within 1 part in 10^6. As a result of many such comparisons it has been verified that the measurements of this observation station can be relied upon to have an accuracy to within at least 1 part in 50 000.

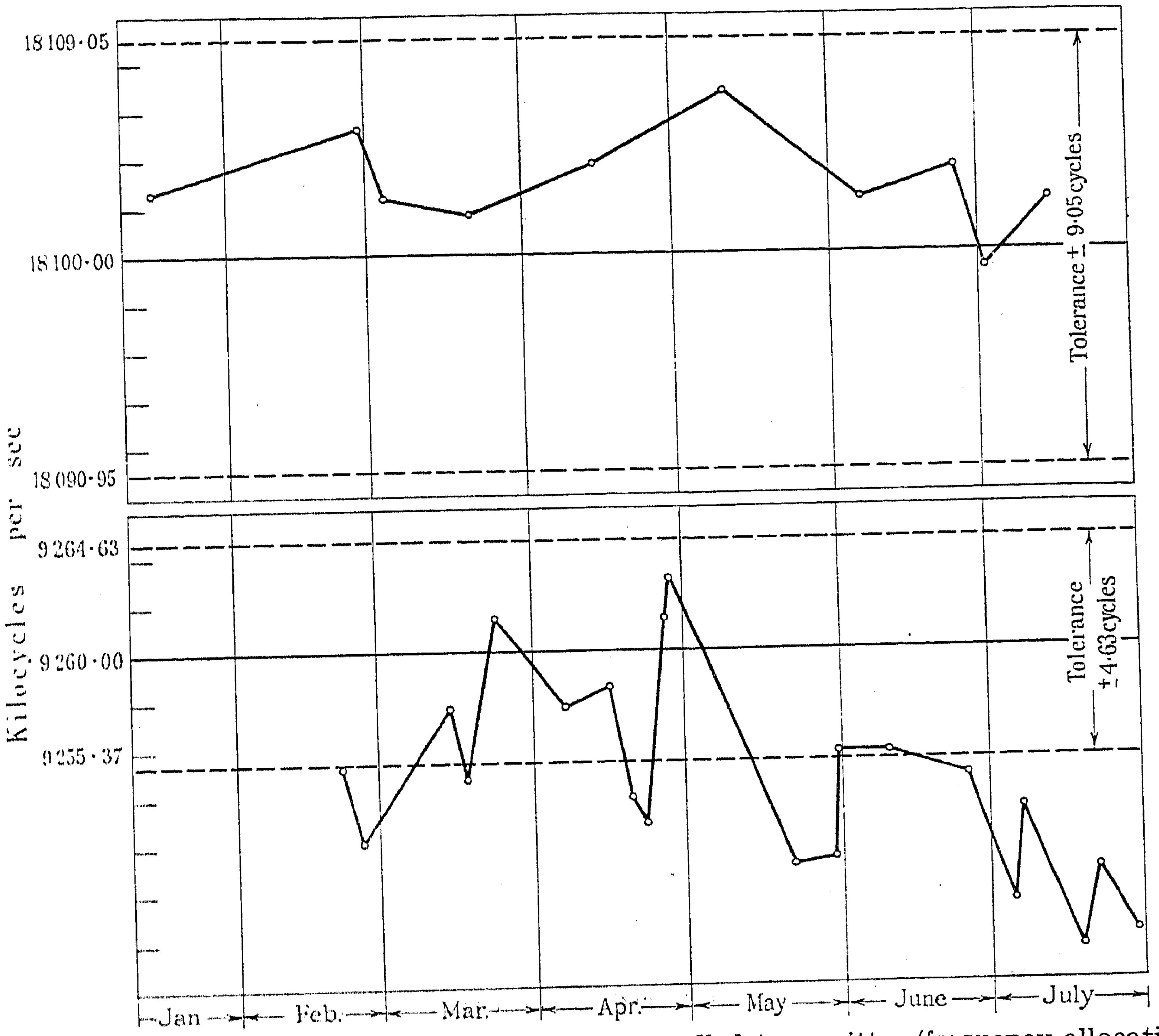

FIG. 12.—Frequency measurements on master-oscillator controlled transmitter (frequency allocations 18 100 and 9 260 kilocycles per sec.) carried out at Colney Heath 11th January–31st July, 1931.

Examples of Frequency Measurement Observations.

To obtain the degree of precision required for the point-to-point services, particularly on those using short-waves, the concentration of frequency determination at a special locality where accurate measurements are possible is definitely preferable to attempting to observe and control the frequency at the transmitting station by the use of wavemeters, and, as has already been stated, one of the purposes for which the frequency-measuring station was installed was for the control of the transmitters operated by the Post Office.

A large number of observations have consequently been made on long-wave, medium-wave and short-wave transmitters to determine the day-to-day variation of frequency and the variations which occur at short intervals.

Some typical results are reproduced and, as a guide to their performance, the limits of tolerance for the appropriate type as recommended by the C.C.I.R. at the Copenhagen meeting are also given.

Tuning-Fork Control.

Fig. 7 shows a series of daily readings on three tuning-fork controlled, long-wave telegraph transmitters, and measurements on the same transmitters taken at frequent intervals during a day's transmission are given

TABLE 1.

Long-Wave Tuning-Fork Controlled.

Transmitter call sign and location	Allotted frequency	Limits of frequency variation (C.C.I.R. recommendation)	Actual variation
	cycles/sec.	cycles/sec.	cycles/sec.
GBV (Rugby) ..	78 000	± 78	+ 4 – 20
GBY (Leafield) ..	51 500	± 51·5	– 2 – 28
GBR (Rugby) ..	16 000	± 16	– 1 – 7

in Fig. 8. The recommended tolerances for this category are ± 0·1 per cent. The performance is summarized in Table 1.

The frequencies of these transmitters are well within the limits at present considered to be permissible. GBV, for example, shows a maximum deviation of 0·025 per cent, the recommended tolerance being ± 0·1 per cent.

Subsequent to April last, when some modifications were made, the deviation from the allotted frequency has never been observed to be greater than 700 cycles in 10 770 000, i.e. 0·0065 per cent or 65 parts in 1 million. This is to be compared with the recommended tolerance of 0·05 per cent at present, or 0·02 per cent for the future.

Records taken at short intervals during the day are shown in Fig. 11.

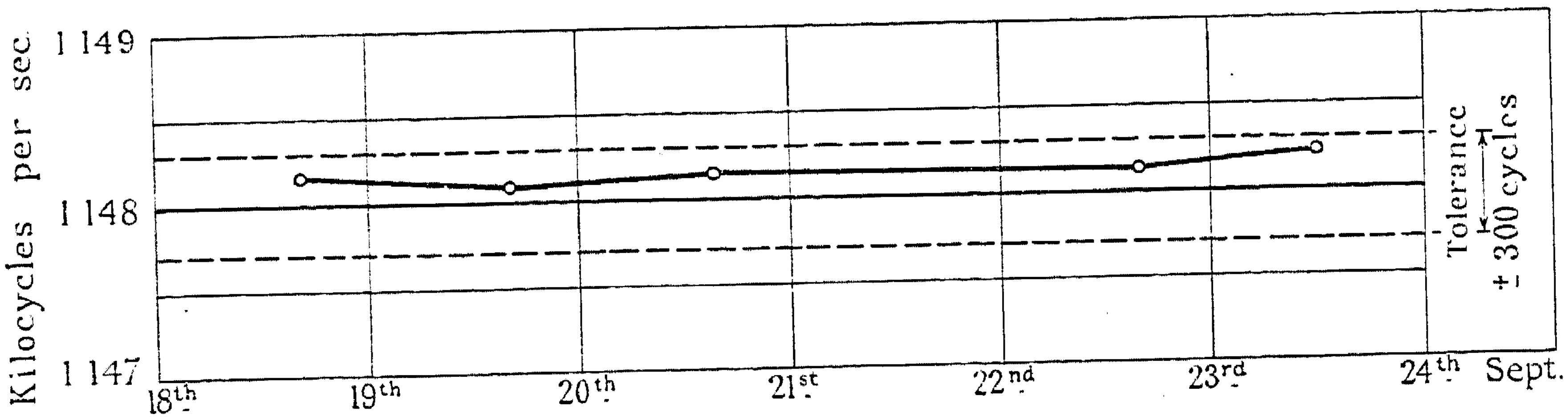

FIG. 13.—Frequency measurements on master-oscillator controlled broadcast transmitter (frequency allocation 1 148 kilocycles per sec.) carried out at Dollis Hill 18th–23rd September, 1931.

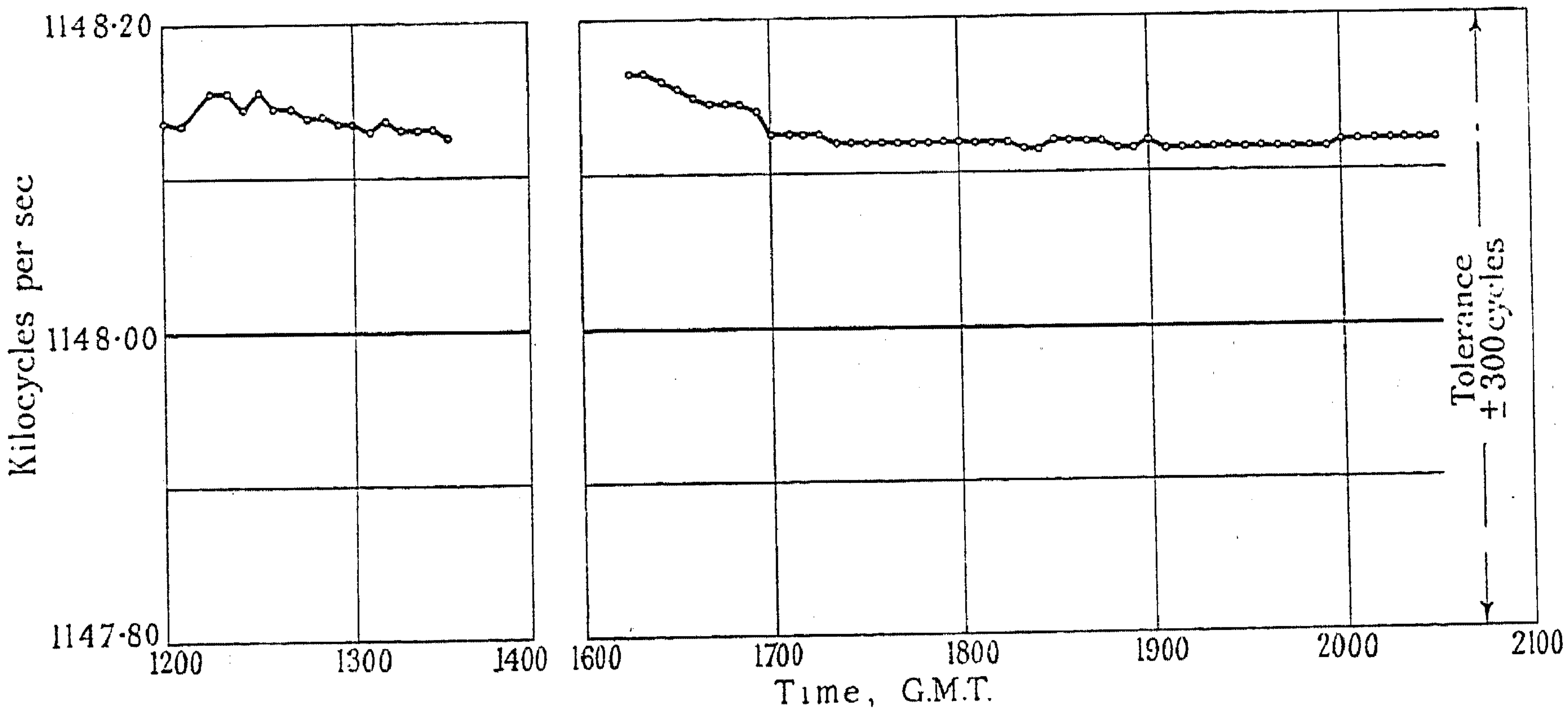

FIG. 14.—Frequency measurements on master-oscillator controlled broadcast transmitter (frequency allocation 1 148 kilocycles per sec.) carried out at Dollis Hill 18th September, 1931.

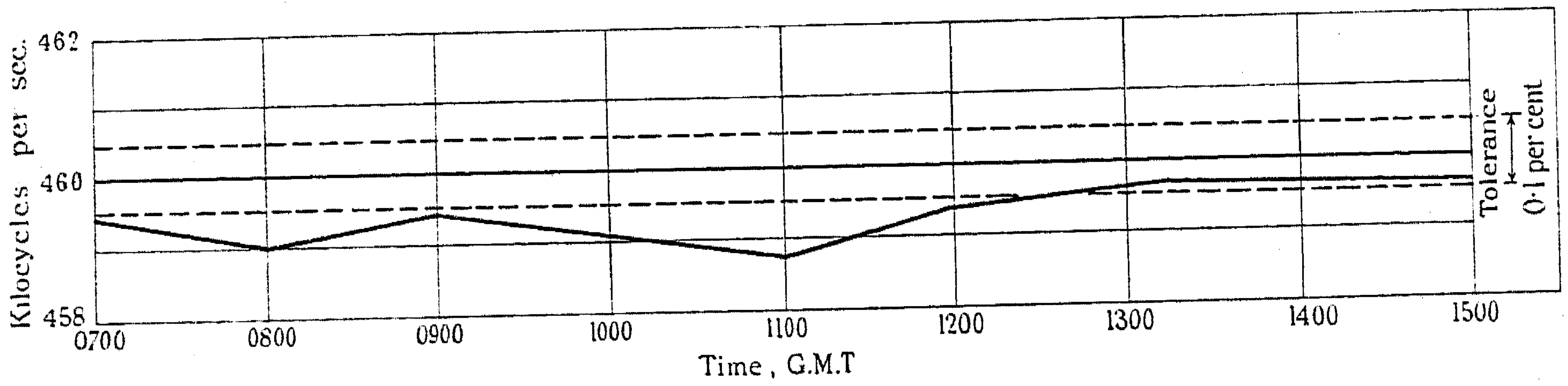

FIG. 15.—Frequency measurements of coast station (frequency allocation 460 kilocycles per sec.) carried out at Dollis Hill 20th September, 1931.

CRYSTAL-CONTROLLED TRANSMITTERS. FIXED-SERVICES TELEPHONY.

The records of two crystal-controlled short-wave telephone transmitters in use on the radio telephone services taken over a period of nine months are shown in Figs. 9 and 10. In the latter figure it will be noted that during the months of March and April three instances of definite changes of frequency occurred. Although large by comparison with the normal performance only one of these changes, however, exceeded the tolerance applicable to this frequency. This was due to a failure in the thermostatic control system.

MASTER OSCILLATOR-CONTROLLED TRANSMITTERS.

Two typical series of observations of master oscillator-controlled, high-speed, short-wave telegraph transmitters are given in Fig. 12. It is interesting to note that the percentage deviation is much less for the transmitter operating at the higher frequency, the deviation being well within the recommended figure of 0·05 per cent. The mean frequency is above the allotted frequency, possibly to minimize interference from another station, and the deviation from the mean frequency is approximately ± 0·02 per cent.

As an example of a medium-wave master oscillator-controlled transmitter, a high-grade broadcasting station has been taken for which the tolerance at present is ± 300 cycles and for the future 50 cycles (see Figs. 13 and 14). The difference from maximum to minimum during a day's run does not exceed 50 cycles on the day for which the observations are taken.

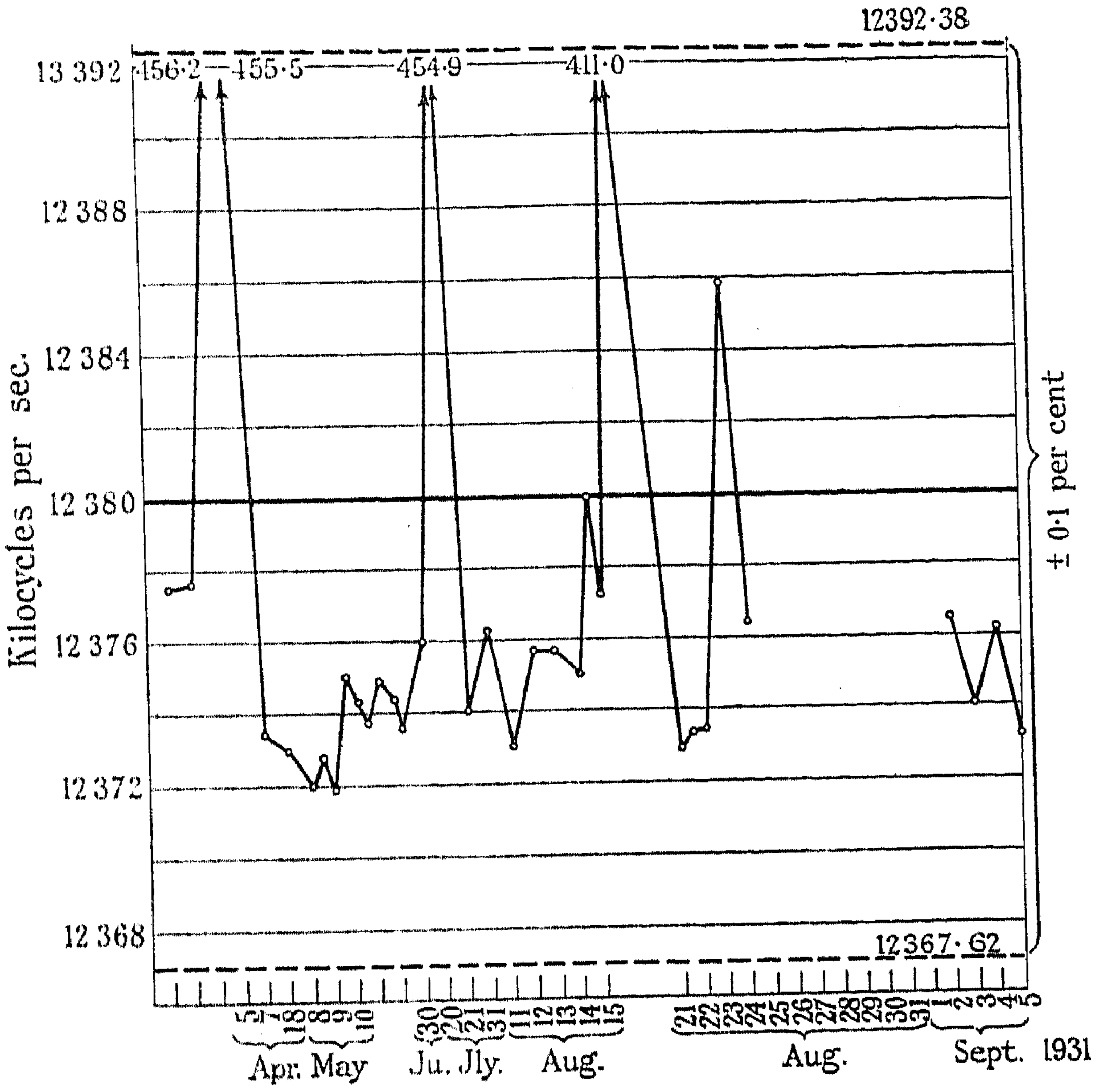

FIG. 16.—Frequency measurements on crystal-controlled ship telephony transmitter (frequency allocation 12 380 kilocycles per sec.) carried out at Colney Heath from 25th February, 1931.

± 0·1 per cent. The mean frequency is slightly off the allotted frequency but the daily variation from the mean frequency does not exceed ± 0·1 per cent.

SHORT-WAVE MOBILE STATIONS.

The choice of ship stations on which measurements of frequency stability can be made is a very limited one.

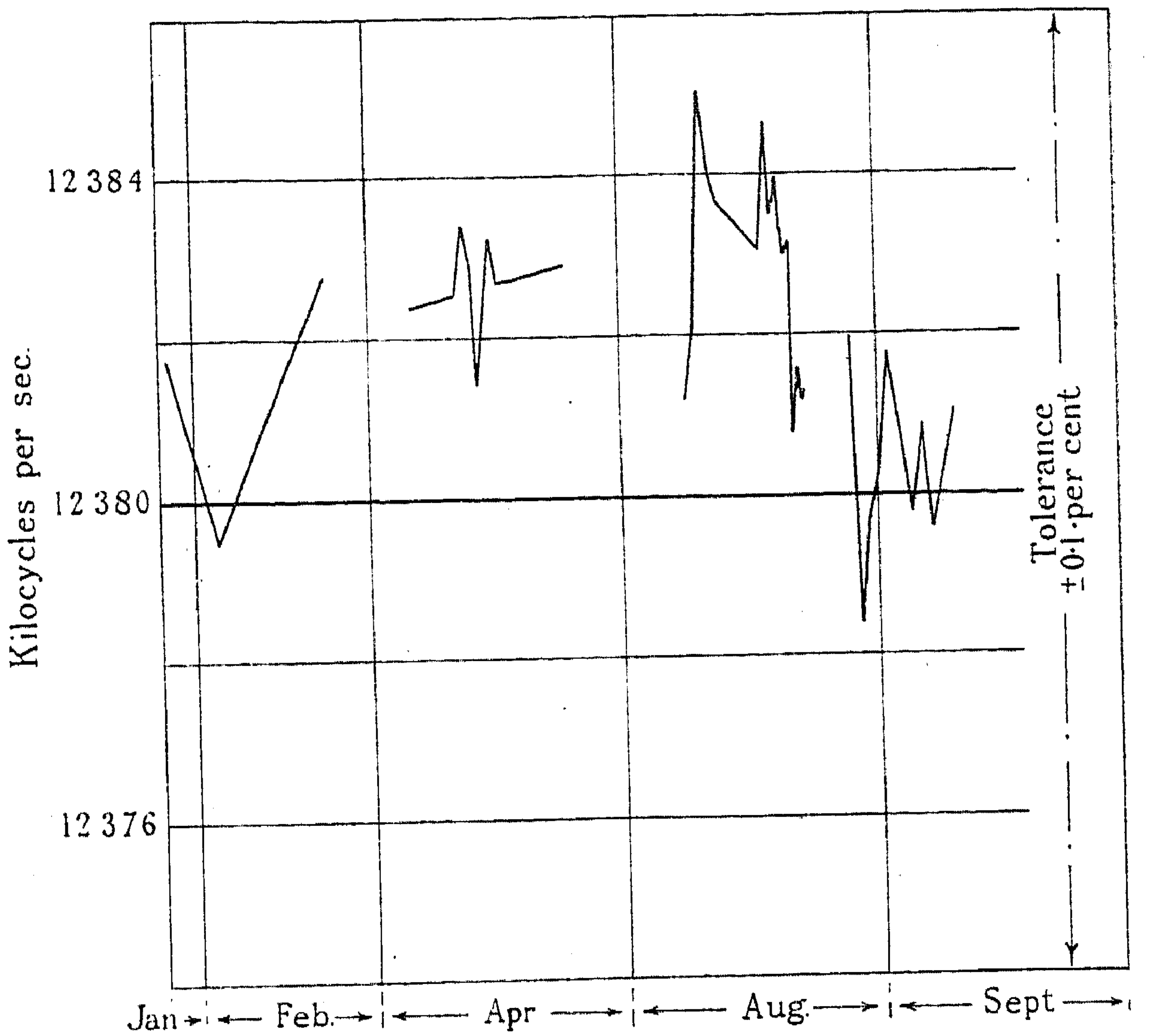

FIG. 17.—Frequency measurements on master valve-oscillator controlled ship telephony transmitter carried out at Colney Heath.

Some samples of the performance of ships fitted with short-wave telephone transmitters of the best modern type have been chosen.

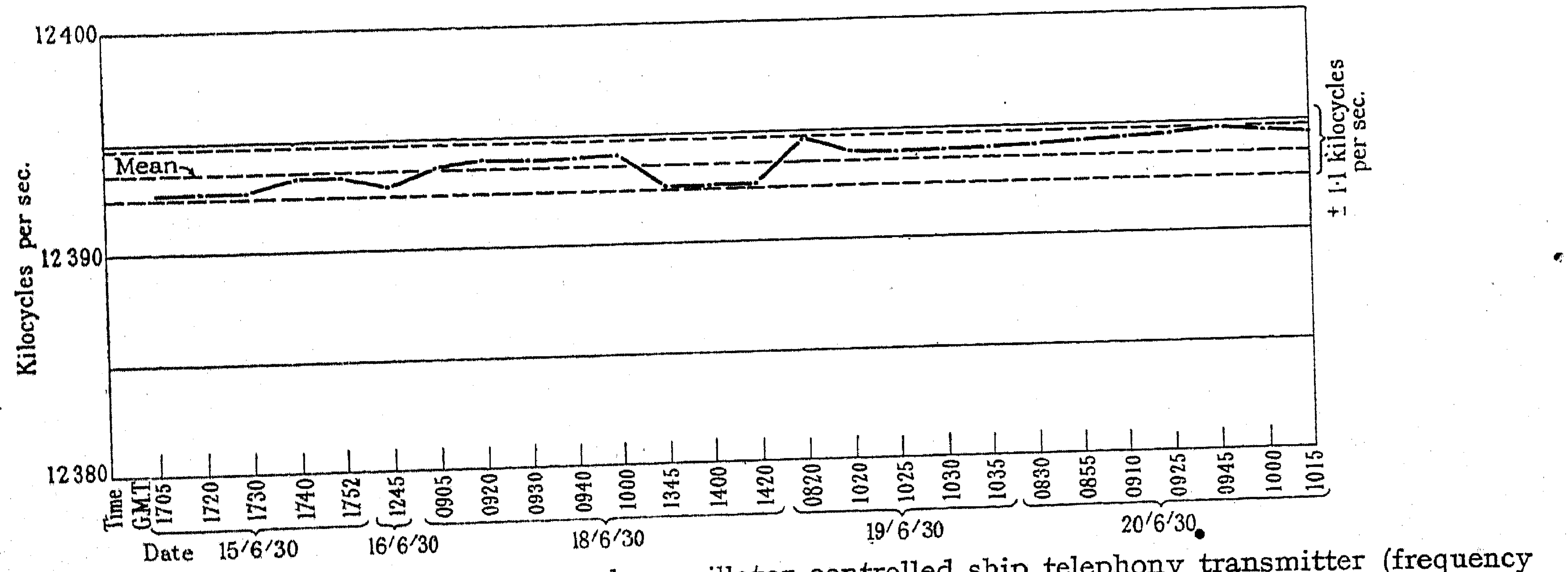

FIG. 18.—Frequency measurements on master valve-oscillator controlled ship telephony transmitter (frequency allocation 12 380 kilocycles per sec.) carried out at Dollis Hill.

Accuracy of measurements = ± 200 kilocycles per sec.
Mean frequency = 12 393·7 " " "
Max. variation from mean frequency = ± 1·1 " " "

VALVE TRANSMITTER. SIMPLE SELF-OSCILLATING CIRCUIT.

The low-power shore stations operating in the mobile band which are now using the continuous-wave system are not generally equipped with master-controlled oscillators and are designed for quick wave-change. Fig. 15 indicates the performance of a modern transmitter of this type for which the tolerance should be

Fig. 16, for a crystal-controlled transmitter, appears to indicate that on three occasions the drive circuit was operating on an alternative mode of oscillation of the crystal circuit; otherwise the operation is well within the recommended limits of ± 0·1 per cent.

Fig. 17, for a master oscillator-controlled transmitter, indicates a variation of less than 0·04 per cent, and Fig. 18 indicates a remarkably good performance as regards variation from mean frequency, although the mean frequency is not within the required limits from the allotted frequency.

Measurements of Interference.

Prior to the formulation of recommendations as to tolerance by the C.C.I.R., the adjustment of complaints as to interference often rested on the interpretation put on the general conditions laid down in the Washington Regulation[*] to the effect: "The waves emitted by a station must be maintained at the authorized frequency, as exactly as the state of technical development permits, and their radiation must also be as free as practicable from all emissions which are not essential to the type of communication effected."

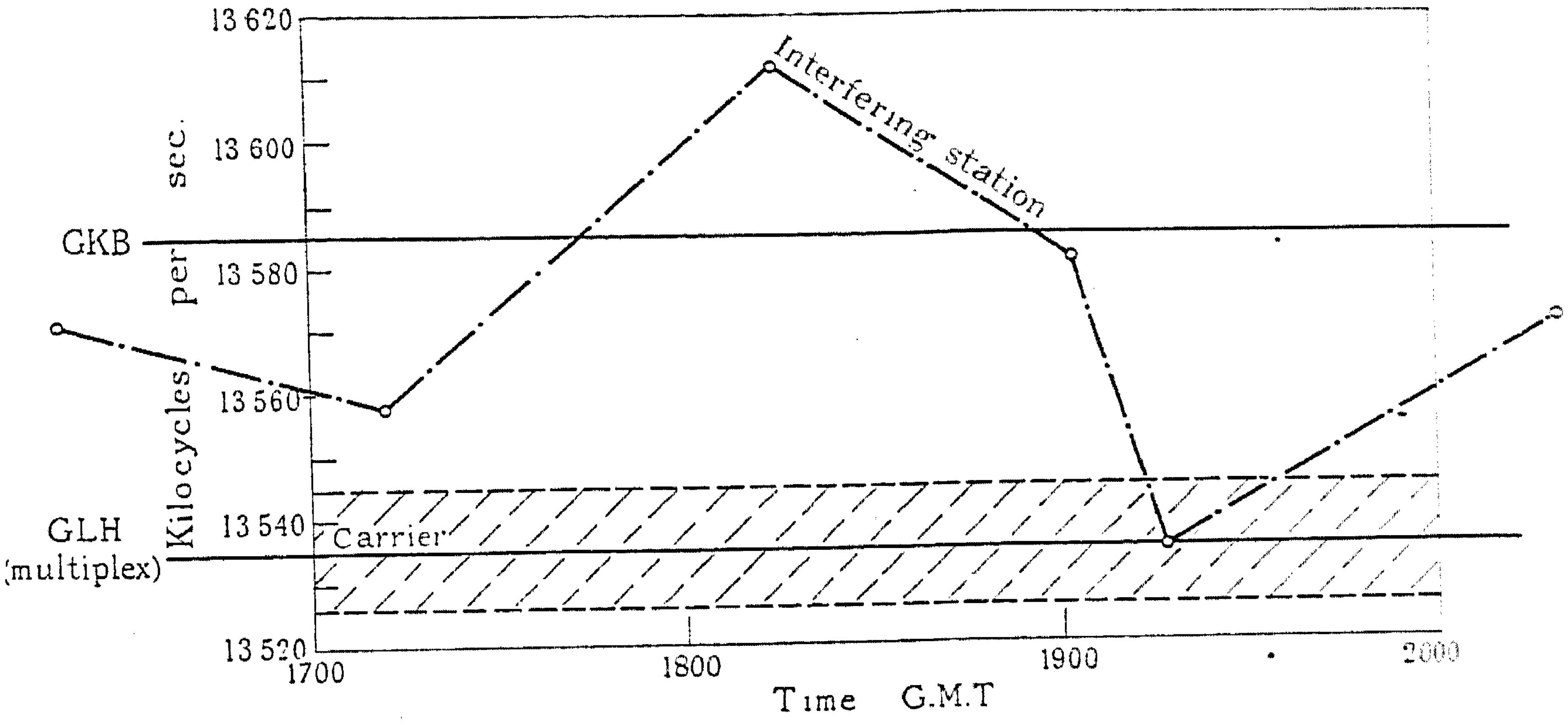

FIG. 19.—Interference with Rugby GKB (frequency 13 585 kilocycles per sec.) and Dorchester GLH (frequency 13 544–13 526 kilocycles per sec.) caused by frequency drift of interfering station, 17th June, 1931.

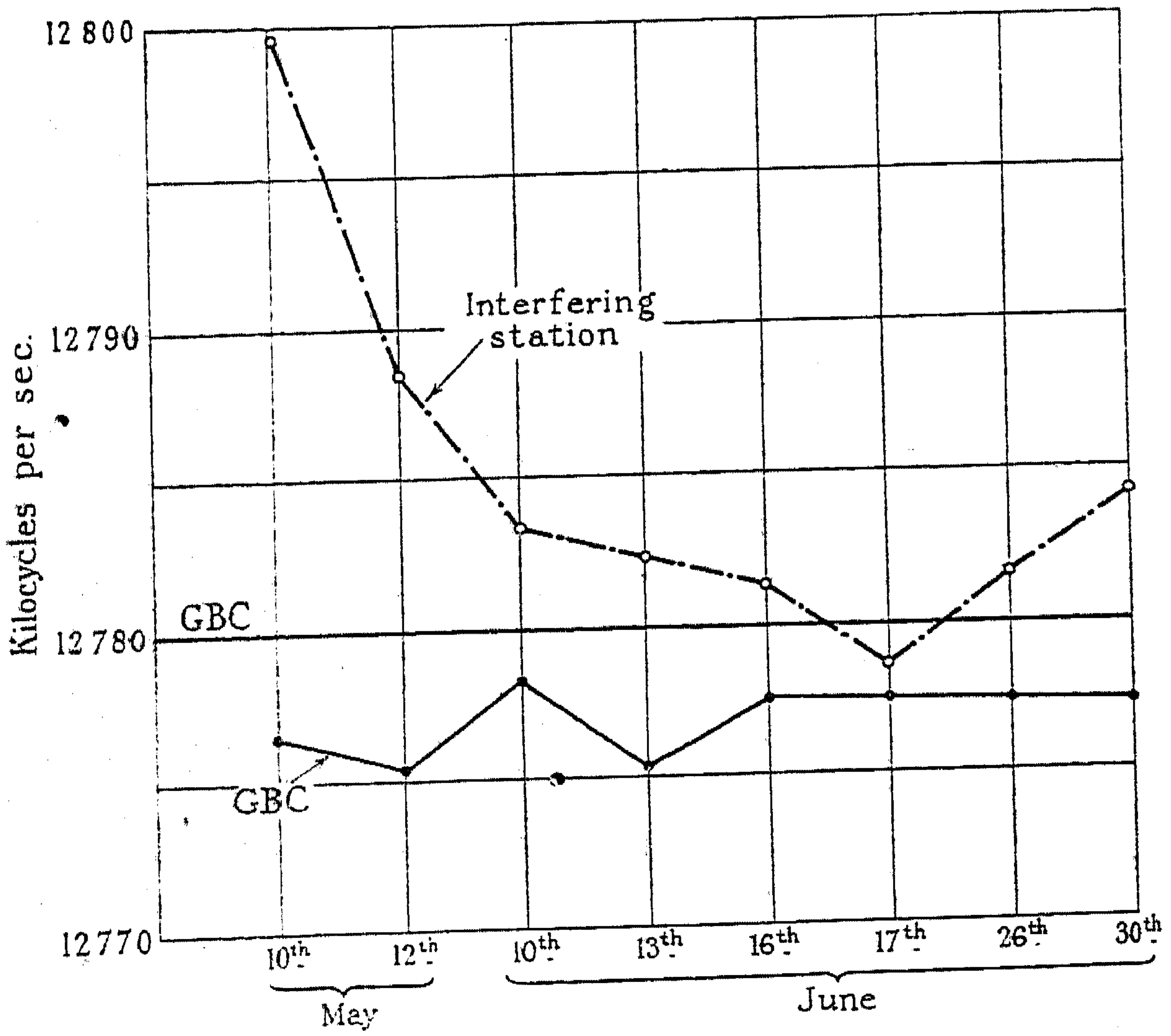

FIG. 20.—Interference with Rugby GBC (frequency 12 780 kilocycles per sec.) caused by frequency drift of land station, May and June, 1931.

With the facilities now available for precise measurements of frequency and the more specific recommendations of the C.C.I.R., which should have almost the weight of regulations, adjustment of difficulties should be more easily effected.

The preliminary step in all cases of reported interference between stations is, wherever practicable, to make a measurement of the frequency of all the stations concerned, and the identification of the stations not working on their assigned frequency. In cases where the interference is intermittent, prolonged observations may be necessary to obtain concrete evidence as to which station is at fault. Some samples of such measurements are given in Figs. 19, 20 and 21 in which the cause of the interference is clearly established as due to frequency variation on a particular station.

It is unfortunately true that many stations of all categories of services are not yet in line with agreed recommendations, and the examples selected are not by any means the worst. Indeed many cases arise where, apart from frequency changes *per se*, the effects of excessive frequency modulation produced either intentionally in order to broaden the transmitted band or inadvertently by reason of imperfect control make it impossible to measure a definite carrier frequency.

I propose to particularize on one category of service—fixed stations operating on short waves. Observations on the performance of short-wave telephone transmitters in use on the radio-telephony services of the Post Office have established that, with thermostatically-regulated piezo-electric control, the maximum frequency variation is of the order of 125 parts in 1 million and can be maintained within these limits continuously throughout the year. Further, a crystal oscillator can be initially adjusted to within 50 parts in 1 million of the allotted frequency, and the maximum variation from the allotted frequency should always be within 115 parts in 1 million. A very reasonable requirement for a high-grade short-wave transmitter may be considered to be a frequency control of ± 150 parts in 1 million or ± 0·015 per cent from the allocation frequency. It may here be noted that the figures recommended by the C.C.I.R. are 0·05 per cent as immediately applicable and 0·02 per cent for the future.

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[*] International Radio-telegraph Convention, Washington, 1927. General Regulations Art. 4, § 2.

Development of Controlled Transmitters as Used by the British Post Office.

With the tuning-fork controlled transmitters the Post Office originally used steel tuning forks, but, as these suffered from frequency variation due to changing temperature, recourse was had to elinvar, which has an exceedingly small temperature coefficient; at the present time all the tuning forks used in the transmitters are made of this material.

The success of this system of tuning-fork control for medium- and long-wave transmitters, as evidenced both by experience derived from maintenance and the results of frequency observations carried out over long periods, encouraged the Post Office early to investigate the possibilities of a mechanical-electrical source for the control of their short-wave transmitters. At the present time all the point-to-point short-wave telegraph transmitters and transoceanic short-wave telephone transmitters are controlled by quartz-crystal oscillators. The results as regards frequency constancy, have already been discussed and it may be of value if the technique which has been developed to ensure constancy of control and of frequency is described in some detail.

A great deal of information has been published on the quartz oscillator, and extensive theoretical and experimental data are available as to the behaviour in relation to the method of cutting and preparing the crystal and in regard to the electrical circuit with which it is associated. A very complete monograph on this subject has recently been published by the Radio Research Board.* The role of the engineer has been to apply such knowledge to the control of large-power commercial transmitters, and to devise suitable arrangements of circuits and methods of testing, successfully to achieve this end.

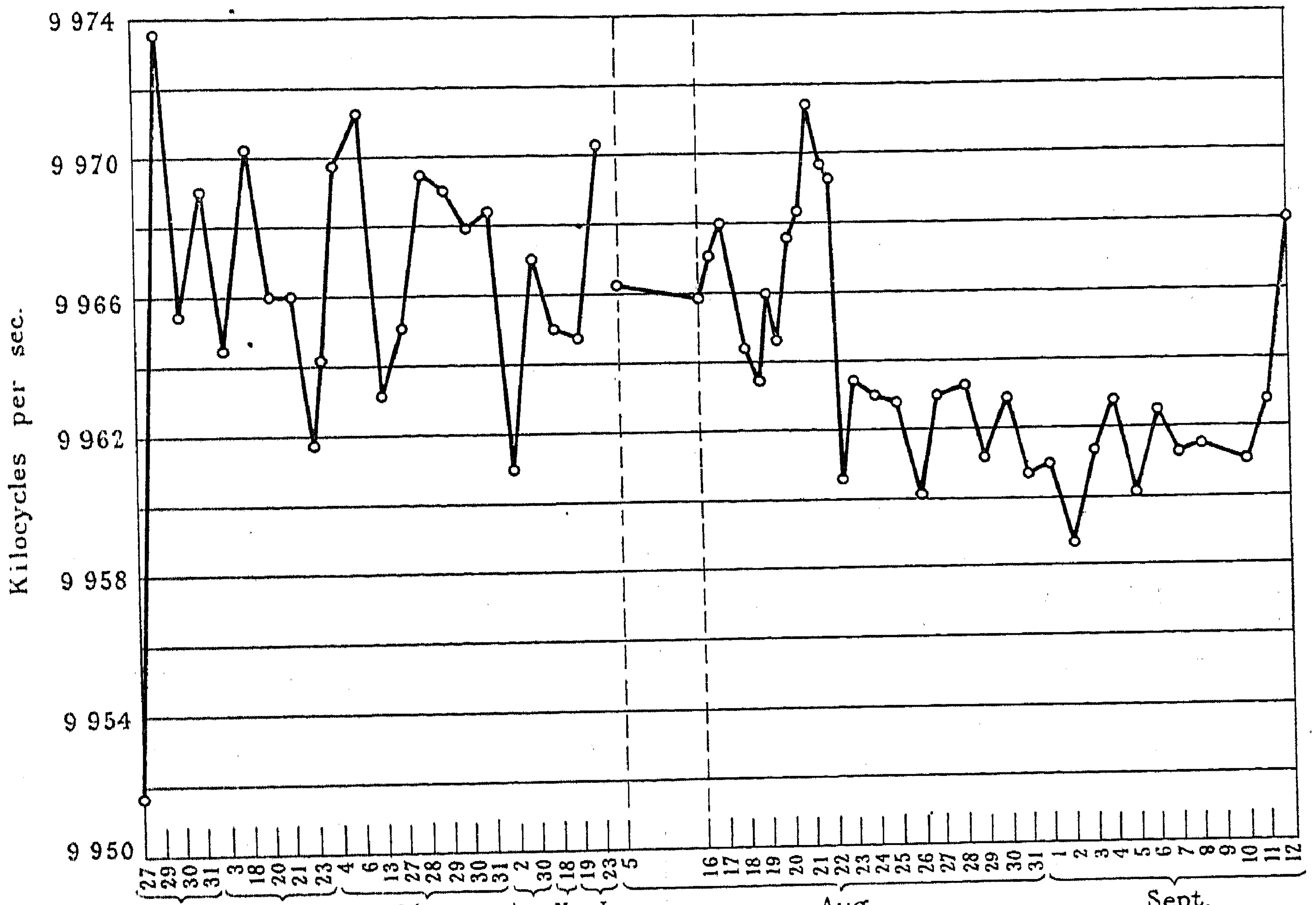

FIG. 21.—Frequency measurements on interfering station (frequency allocation 9 970 kilocycles per sec.) carried out at Colney Heath from 27th January, 1931.

The problem resolves itself into the production of a crystal oscillator having a sufficient power output to control a moderate-power amplifier unit without excessive intervening stages, and capable of being set within, say, 50 parts in 10^6 from its allocated frequency. It should also, whilst in operation, maintain this frequency to, say, 100 parts in 10^6 whatever the variation in temperature. To ensure this the circuits used must not react back on the crystal oscillator and by this means vary its frequency of oscillation.

In the case of quartz crystals the same problem of frequency variation with temperature is encountered, but it is complicated by the fact that a quartz plate such as is used in short-wave transmitters behaves differently, both as regards its response frequency in relation to its thickness and its frequency variation with temperature. These variables depend on the mode of cutting the plate from the solid crystal. The difference is accentuated by the appearance of unwanted modes of vibration in different magnitudes in the two common forms of cut of the quartz oscillator.

In their earliest transmitters the Post Office used plates cut in the manner known as the "Y" cut, i.e. with the contact planes parallel to the electric axes of the quartz crystal. These oscillators were mounted with the exciting electrodes in contact with the faces of the crystal, and there was no temperature control. The alternative form of cut, the "X" cut, is with the contact planes perpendicular to the electric axis. The average temperature coefficient of the "Y"-cut crystal is of the order of 70 to 80 parts positive per million per degree C. rise in temperature, whilst that of the "X" cut is of the order of 20 parts negative per million per degree C. rise in temperature. This factor and the further important one that unwanted modes of oscillation were less frequent with the "X" cut than with the "Y" cut led to the adoption of the "X" cut as the standard for Post Office transmitters. In order to minimize change of frequency with temperature, the crystal with its associated circuit is maintained in a thermostatically controlled oven and the temperature is maintained constant to about ± ¼ deg. C. With "X"-cut crystals, therefore, the frequency change on account of temperature should not be greater than about ± 5 parts in 10^6. It may be of interest to note that the thermostatic control of the ovens in the latest transmitters makes use of a Wheatstone bridge thermometer, in association with a galvanometer and selenium cell, for controlling the incidence of the heating.

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* P. Vigoureux: "Quartz Resonators and Oscillators," H.M. Stationery Office.

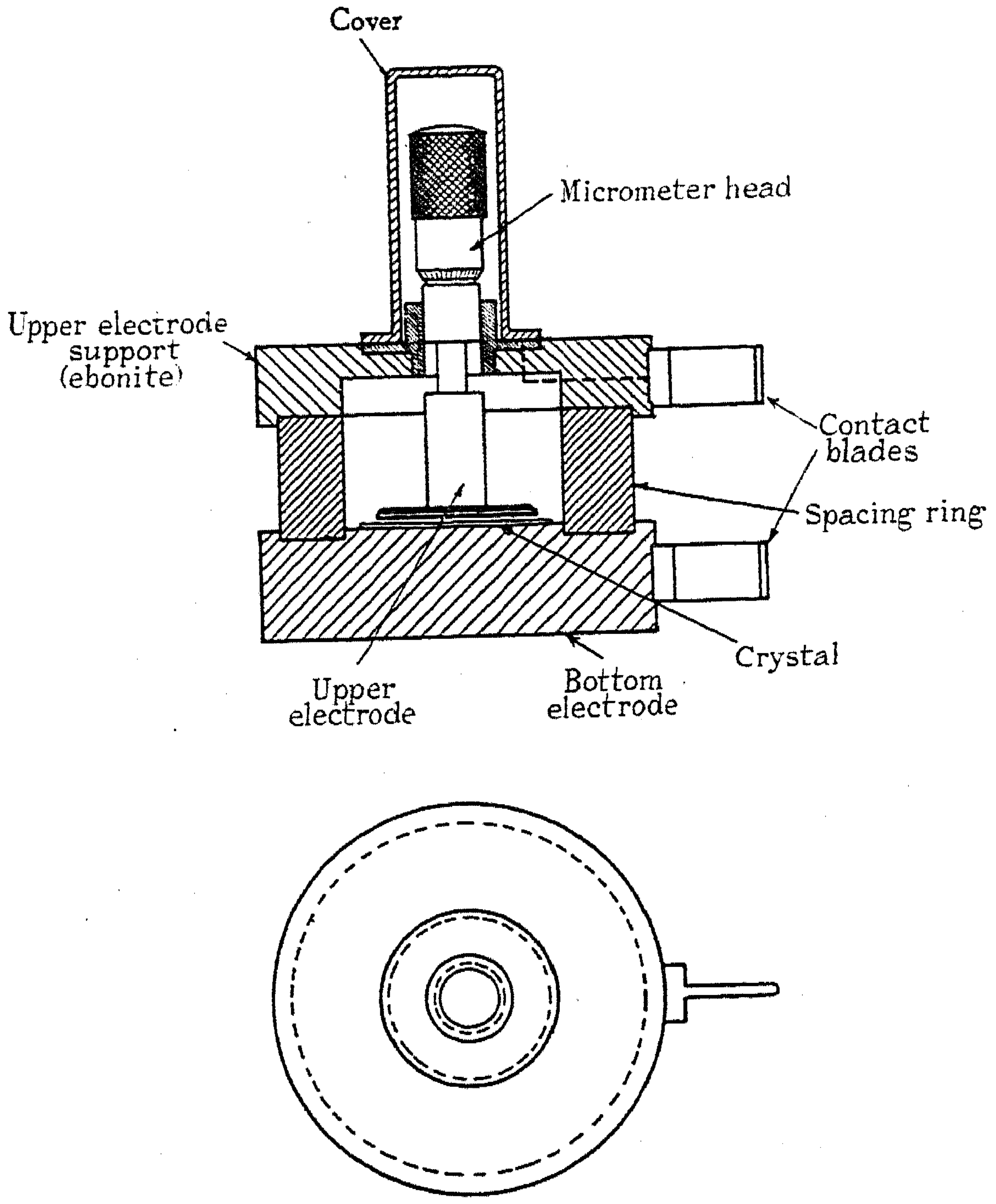


FIG. 22.—Type of crystal holder in present use.

The quartz oscillators are made up in the form of square plates of 1 in. side with the edges rounded in order to reduce unwanted oscillations, and the thicknesses used vary from about 0·5 mm to 1·5 mm. In order that the crystal can be adjusted to oscillate to within relatively a few cycles of the required frequency the Post Office standard practice is to use an air-gap between the upper electrode and the top surface of the quartz oscillator, and to adjust the position of the upper electrode by means of a micrometer screw. The actual type of holder in use at present is illustrated in Fig. 22. This is the most satisfactory design of many which have been tried up to the present. Tests are being carried out in connection with the development of a holder which is automatically compensated for temperature, and also in connection with the minimization of the effects of air-gap resonance.

Referring to Fig. 22, the bottom electrode and the upper electrode support each have a contact blade attached and are separated by the brass spacing ring. The upper electrode support carries a micrometer head to which is attached the upper electrode. The crystal plate rests freely on the lower electrode and is slightly smaller across the diagonal than the diameter of the spacer. The crystal operates with an air-gap which can be adjusted to 0·1 mil by means of the micrometer. The air-gap adjustment is determined before the transmitter is placed in operation for commercial service, and the cover is screwed down to prevent subsequent alterations to the air-gap, the width of which is usually of the order of 0·003 in.

Besides the advantage that with the use of the air-gap type holder the initial adjustment of frequency is easily effected, there is the fact that possible variations of frequency due to rubbing on the electrodes, which may be appreciable with contact electrodes, are eliminated.

The form of valve circuit associated with the quartz oscillators is shown in Fig. 23. It comprises a tuned anode circuit with the crystal connected between the grid and filament. The anode voltage applied to the valve is 120 volts and the power output is such that the heating effect of the high-frequency currents through the crystal is small. The whole of the oscillator circuit is contained within the thermostatically controlled oven, and when once the circuits and crystal air-gap are set to give the correct frequency the control circuit is maintained without any further adjustments.

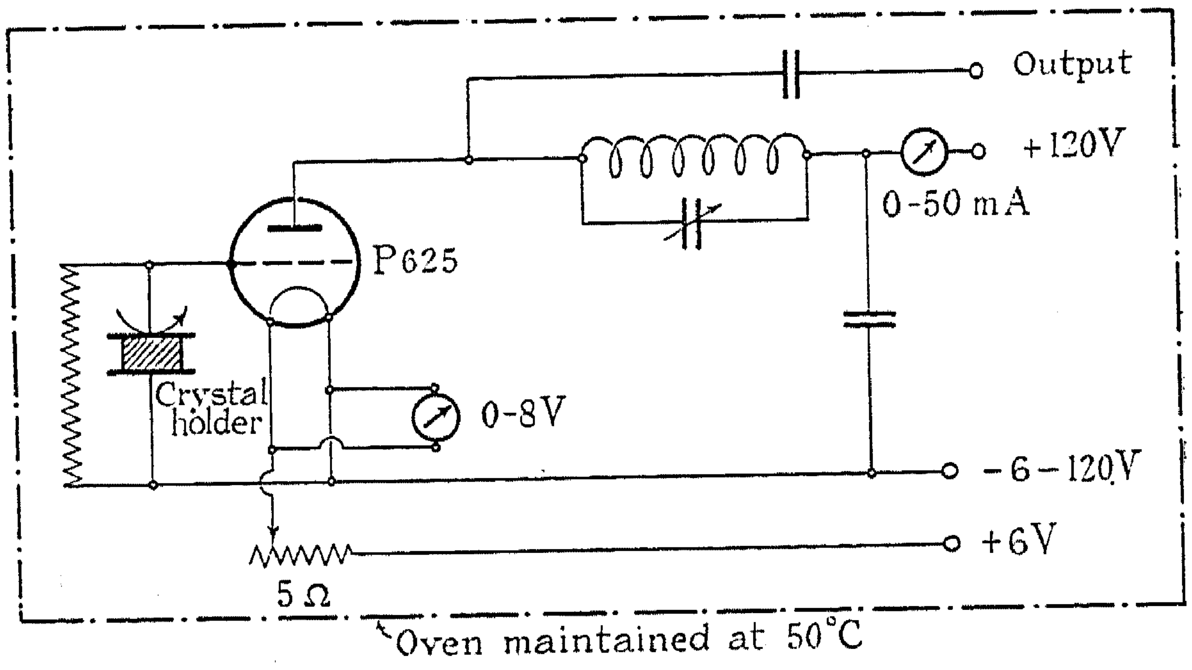


FIG. 23.—Valve circuit associated with quartz oscillators.

The frequency measurements which have been carried out in the latest Post Office quartz-controlled transmitters indicate, as previously stated, that a frequency constancy to within 115 parts in 10^6 of the allocated frequency is readily attainable over prolonged periods.

The preceding description deals with the mounting of the crystal, the form of the control circuit and the maintenance of steady temperature conditions. Before the quartz plates are put into service in the transmitters, however, routine tests are carried out in the Radio Laboratory in order to determine whether they deviate in any marked way from the average standard which has been determined. The tests include measurement of temperature coefficient, wave constant, frequency change with air-gap, oscillation in a standard circuit at working temperature, and resonance response over a wide range of frequencies bounding the oscillation frequency. In order to carry out these tests two distinct sets of apparatus are available. One set of apparatus comprises a standard oscillator mounted in a thermostatically controlled oven which is associated with the frequency measurement equipment held at Dollis Hill and a reference to the description of which has previously been given. Frequency measurements can thus be readily made which are accurate to 1 part in 10^6.

TABLE 2.

"X"-Cut Crystals.

Fundamental frequency (nominal)	Temperature coefficient, parts in 10^6	Wave constant, metres per mm	Air-gap constant *
kilocycles/sec.			
1 726	−21·5	104·6	—
2 052	−21·0	105·3	110
2 105	−18·0	105·1	120
2 160	−22·5	105·1	95
2 305	−20·5	104·6	85
2 371	−21·5	104·6	—
2 435	−21·5	104·5	100
2 455	−22·0	104·7	95
2 620	−22·5	104·5	—
2 740	−22·0	104·5	—
2 995	−22·5	104·5	—
3 388	−22·0	104·7	120
4 655	−20·5	106·1	—

* Air-gap constant is defined as: Change of frequency in parts of 10^6 per mil variation from the mean air-gap of 0·002 in.

Table 2 gives the results of measurements upon a batch of crystals which have recently passed through the Laboratory. The crystals were contained in the standard type of holder but it was arranged for the temperature coefficient tests that the upper electrode rested without constraint upon the upper surface of the crystal plate. The test for temperature coefficient was carried out between 40° C. and 50° C., the latter being the actual temperature at which the oven is maintained in practice, and it was found that the frequency variation was in all cases linear with temperature over this range. The results shown in Table 2 are exceedingly interesting in that they illustrate the constancy of characteristics of this particular batch of quartz plates, which were made up from two consignments from the same supplier. It may be mentioned here that in order to ensure that the crystal oscillator shall have an oscillation frequency as close to the assigned frequency as can be economically obtained, the final grinding of crystals is carried out in the Radio Laboratory.

Prior to tests such as have been illustrated the crystal is tested for oscillation frequency and output in the standard circuit. If it is satisfactory as an oscillator it is then further studied upon the foregoing lines. It has been found, however, that crystals may withstand these tests and yet be liable to instability after they have been subjected to actual working conditions. In order, therefore, further to extend our knowledge of the crystal, an elaboration of the "crevasse" method of exploring the frequency characteristics for the crystal as a resonator has been devised whereby responses over a wide frequency region bounding the oscillation frequency are obtained. To do this the crystal in its holder is mounted in a thermostatically-controlled oven maintained at a temperature of 50° C. and is joined across the condenser of a tuned circuit, the circuit in turn being weakly coupled to an oscillator. The main condenser of the tuned circuit of the oscillator has a specially constructed small condenser in parallel. This small condenser has a total capacitance of 12 $\mu\mu$F and is controlled by a micrometer head so that the changes in capacitance which can be read in the micrometer scale cause relatively small variations in the oscillator frequency. Across the condenser of the first tuned circuit is also connected a valve voltmeter enabling the voltage across the condenser to be observed for any particular excitation. The circuit connections are indicated in Fig. 24.

The procedure of taking a resonance response curve is to set the tuned circuit to approximately the frequency of oscillation of the crystal and then record the readings of the voltmeter corresponding to the various values of the condenser of the oscillator. The frequency range thus covers frequencies both above and below the oscillation frequency of the crystal. Great care is necessary

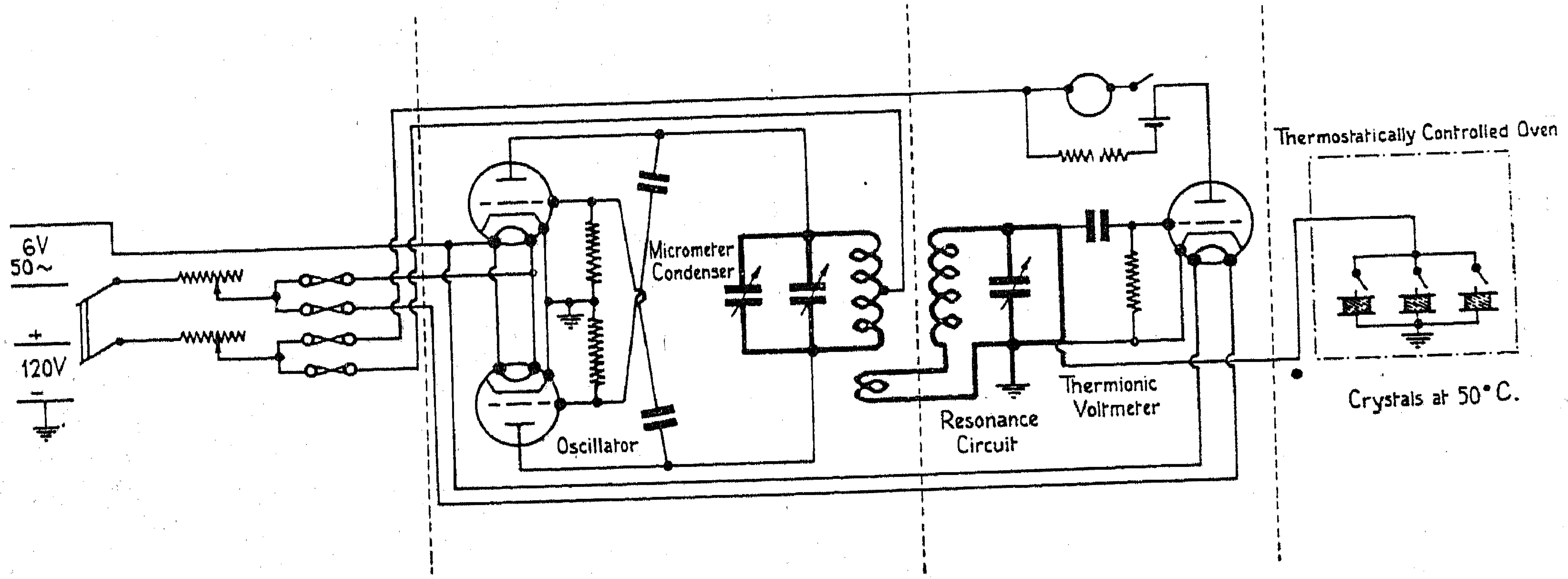


FIG. 24.—Circuit connections for testing crystals.

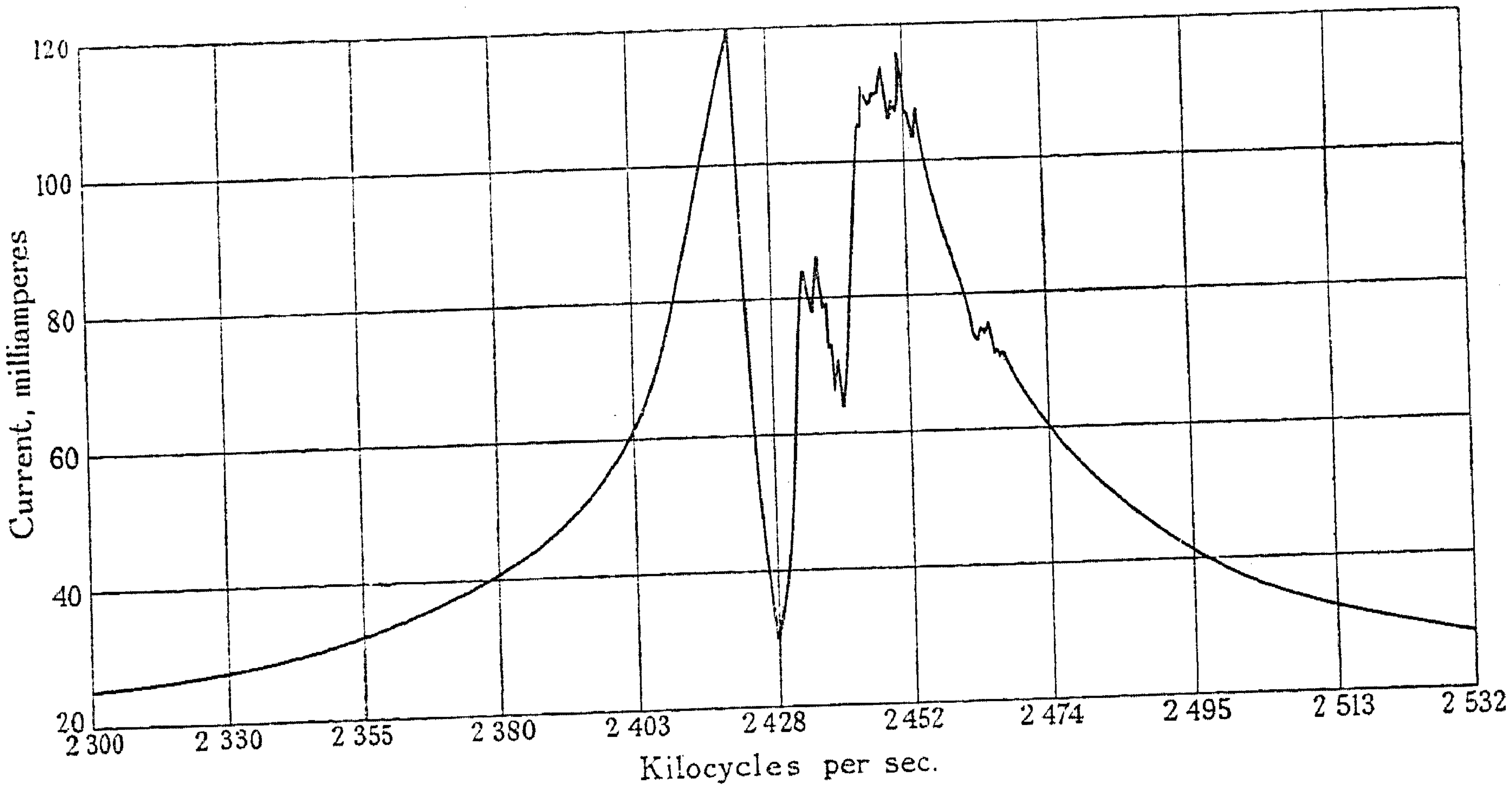


FIG. 25.—Curve obtained with good type of crystal having only one major response curve.

Crystal frequency 2 427·5 kilocycles per sec.
Frequency range 2 300–2 532 kilocycles per sec.
Main frequency 2 428 kilocycles per sec.
Temperature 50° C.

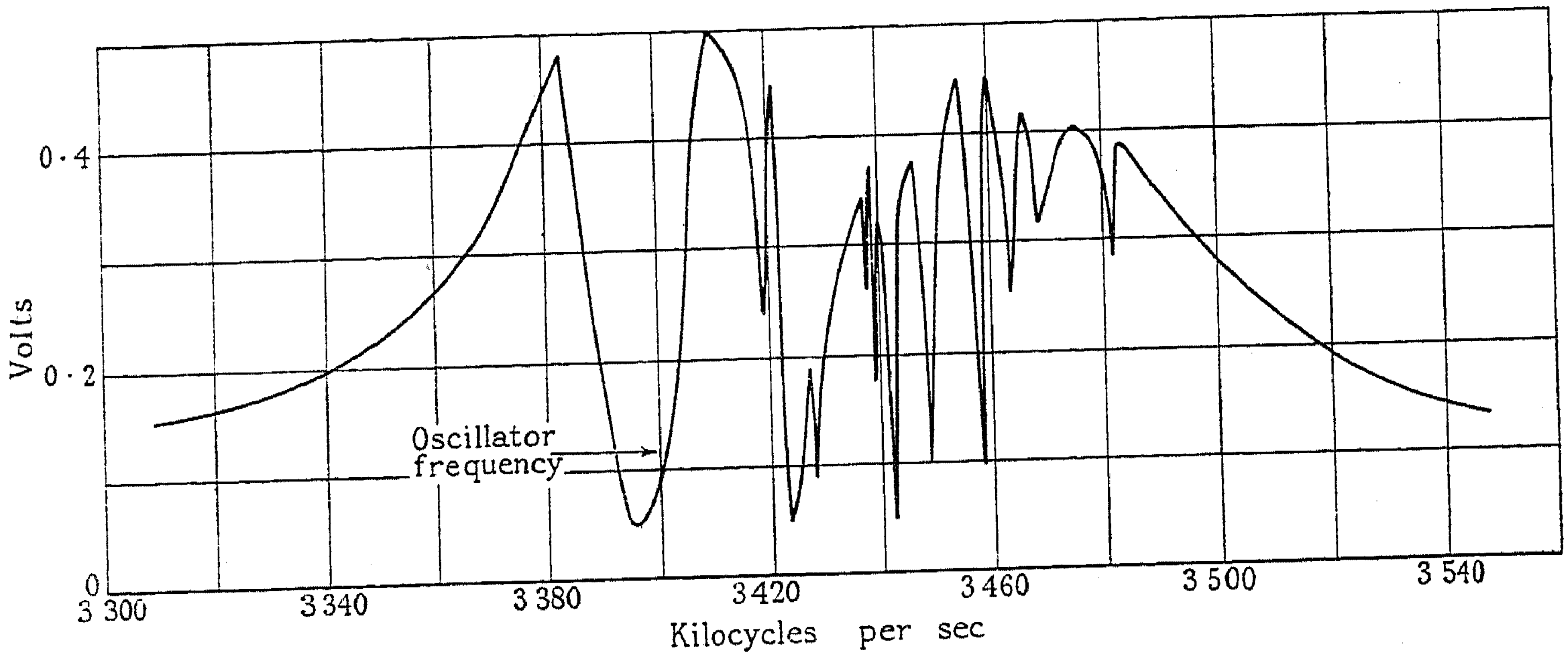


FIG. 26.—Curve obtained with crystal having very complex responses.

Crystal frequency 3 399·8 kilocycles per sec.

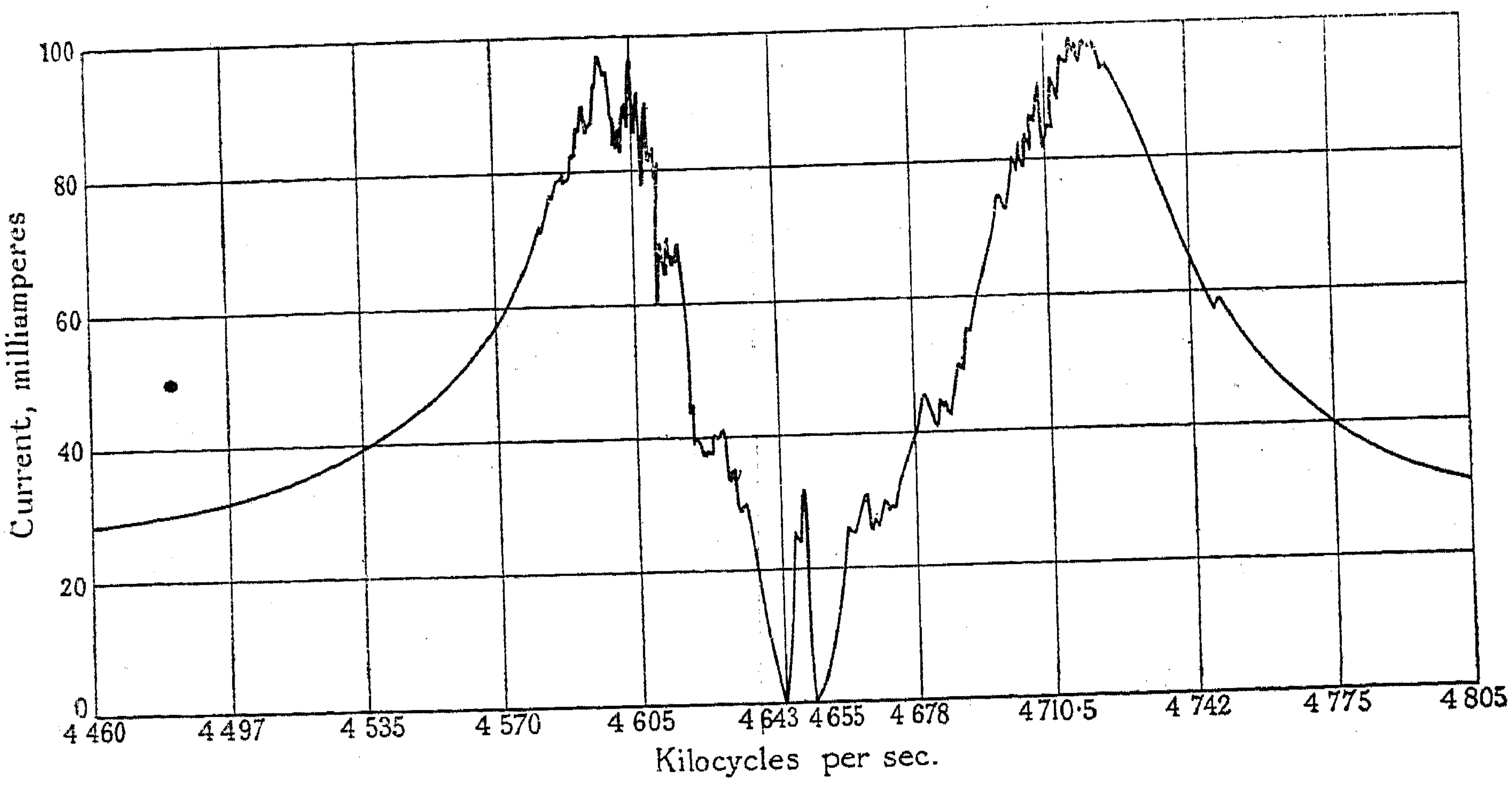


FIG. 27.—Curve obtained with crystal having two major resonances in close proximity.

Crystal frequency 4 655 kilocycles per sec.
1st crevasse 4 643 kilocycles per sec.
Frequency range 4 460–4 805 kilocycles per sec.
2nd crevasse 4 655 kilocycles per sec.

to make the operation of frequency change so slow that all the possible responses are recorded.

Four typical response curves are reproduced. For example, Fig. 25 illustrates the curve obtained with a good type of crystal having but one major response curve. Fig. 26 illustrates the curve obtained with a crystal having very complex responses. In a suitable circuit, where no alteration of any circuit or supply associated with the crystal is made under operating conditions, it would operate satisfactorily at the one frequency indicated on the diagram. Fig. 27 is the curve for a crystal having two major resonances in close proximity; this was found to alternate readily at either of these frequencies, depending on the circuit tuning. Fig. 28 illustrates the curve obtained with a bad crystal which was one of a batch all exhibiting similar qualities. The major resonance will be seen to be very rounded at the bottom and not a sharp crevasse. When tested in a transmitter this crystal actually oscillated on a band of frequencies 2 288·9 to 2 289·8 kilocycles per sec.

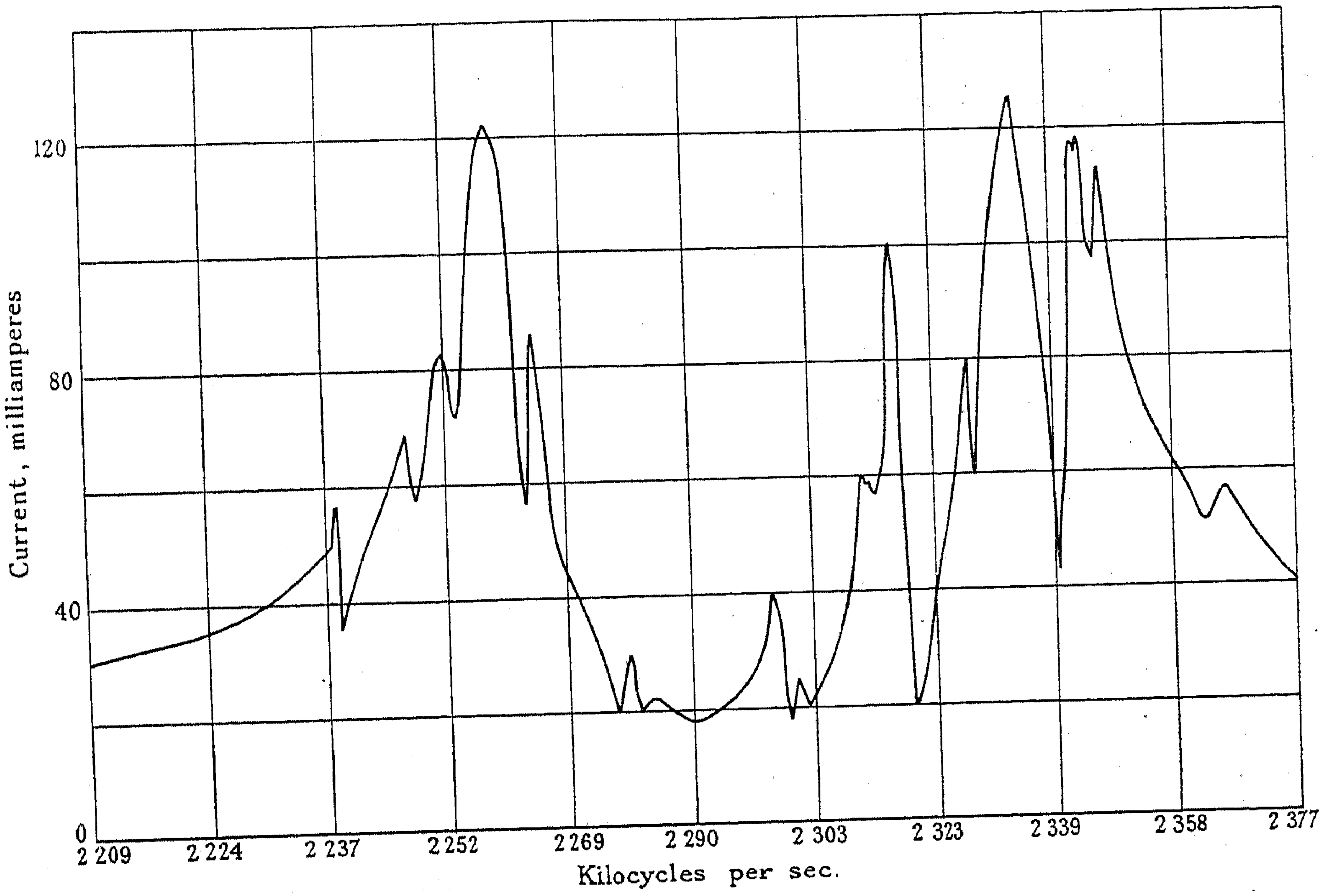


Fig. 28.—Curve obtained with bad crystal.

Crystal frequency 2 288·9 kilocycles per sec. Temperature 50° C.

The peculiar irregularities which are often disclosed in these tests are sometimes difficult to account for in view of the apparent optical regularity of the specimens, but the results are of great practical value since they enable a prediction to be made as to whether and under what condition the crystal is likely to give a satisfactory performance in practice.

Stability of Amplifier Stages.

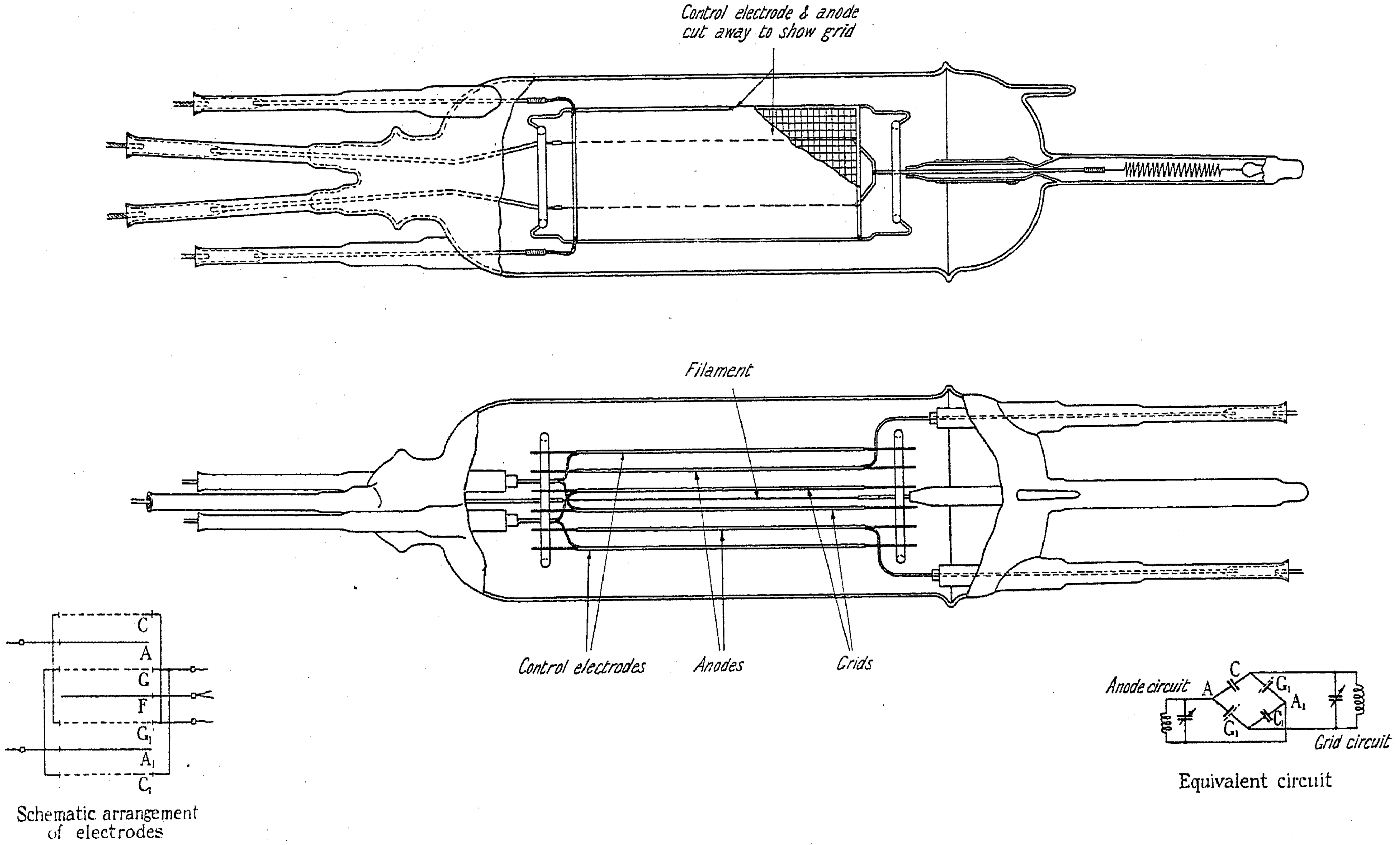
Whatever pains are taken to ensure constancy of frequency of the control circuit—and this applies to any form of control—the work is to a large extent negatived unless steps are taken to prevent reaction back into this circuit from the subsequent amplifier stages of the transmitter. It is usual to mount the amplifying stages of a transmitter in screened compartments with a symmetrical arrangement with regard to earth potential. This is usually achieved electrically by the use of the double-acting or "push-pull" type of circuit, and mechanically by arranging the apparatus symmetrically with regard to the centre-line of the transmitter framework. The problem has been simplified by the development by the Post Office of a special type of valve, for use in high-frequency amplifying stages, which incorporates the advantages of the double-acting principle and minimum reaction from the output to the input circuits. The valve consists of two similar systems of electrodes arranged symmetrically about a single cathode and so connected that reaction potentials from the output to the input of one-half of the valve are counterbalanced by equal and opposite potentials transferred from the output of the other half of the valve.

In its simplest form the valve consists of a loop filament, two control grids, two anodes and two stabilizing grids in the form of flat electrodes symmetrically placed with regard to the control grids on the opposite side of the anodes. Each control grid is cross-connected to the stabilizing grid outside the anode on the opposite side of the valve.

A general view of one type of such a valve is shown in Fig. 29, together with the schematic arrangement of electrodes and its equivalent circuit. The valve having seven electrodes takes its place in the usual nomenclature under the name "heptode." It will be seen that the equivalent circuit is a capacitance bridge in which the leads joining the equivalent condenser have no length at the output junctions and minimum possible length at the input junction. Such valves have been produced for a range of outputs, and considerable experience under actual working conditions has been obtained with the former type.

DEMOUNTABLE VALVES.

It will, I think, be appropriate here to refer to a development in valves of the demountable type which so far has only been applied to long-wave telegraphy but appears to have possibilities for use in the larger-power short-wave type of telephone transmitter. One form of demountable valve was described in a paper* read before this Section on the 4th May, 1927, when its power was limited to about 30 kW. This type of valve has recently been further developed in France to powers of the order of 150 kW.† The result of extensive research and experiment in this country has been the production of a new type of continuously evacuated demountable valve having a power rating of 500 kW.



Schematic arrangement of electrodes

Equivalent circuit

FIG. 29.—Special type of valve for use in high-frequency amplifying stages.

To those wireless engineers whose early training and experience was associated with low-frequency electrical engineering the elimination of the comparatively fragile glass envelope and the substitution of the more robust combination of steel, copper and porcelain must always have seemed to be a desirable attainment. This, combined with the possibility of making replacements of the electrode system by ordinary engineering methods and workshops tools and the concentration of large high-frequency power in one unit, are the most promising features in this development.

The general arrangement of this valve has already been described in the technical Press, and members will have had an opportunity of examining it at the Faraday Centenary Exhibition. I propose to indicate some of the details in its design which appear to be of special interest, and the results of a few preliminary tests which have been made on the valve at Rugby.

Assembly of the Valve and Pumping Plant.

The assembly of the valve is shown in cross-section in Fig. 30. The pumping system has a large reservoir, on the high-vacuum side of which the valve itself is mounted in a vertical position. The reservoir consists of a horizontal cylindrical drum with a large opening in the top having an accurately ground flange. Mounted on this in succession are:—

(1) A 12-in diameter porcelain ring serving as an insulator between the reservoir and the anode.

(2) The anode with detached flanges at either end.

(3) A porcelain ring insulating the anode from the grid assembly.

(4) The grid flange, from which is suspended the grid assembly.

(5) A third porcelain ring insulating the grid from the filament assembly.

(6) The filament assembly.

The joint between each element is accurately ground. Permanent joints are sealed with a special bitumen product (Apiezon wax); others, which are required to be broken to make replacements of filaments, are sealed with vacuum grease. In order to keep the grease joints on the anode cool the anode flanges are water-cooled.

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* C. F. ELWELL: "The Holweck Demountable Type Valve," *Journal I.E.E.*, 1927, vol. 65, p. 784.

† *Comptes Rendus*, 1931, vol. 193, p. 151.

The anode is of steel. It is approximately 24 in. long and in cross-section internally is in the form of a polyfoil forming 9 horseshoe shaped foils approximately $1\frac{1}{2}$ in. dia. on a pitch-circle diameter of 9 in. Each foil has its own grid and filament. The anode is cooled by water circulating through holes drilled lengthwise through the anode. The thickness of the metal between holes is $\frac{1}{8}$ in. and between the holes and the inside of the anode is also $\frac{1}{8}$ in.

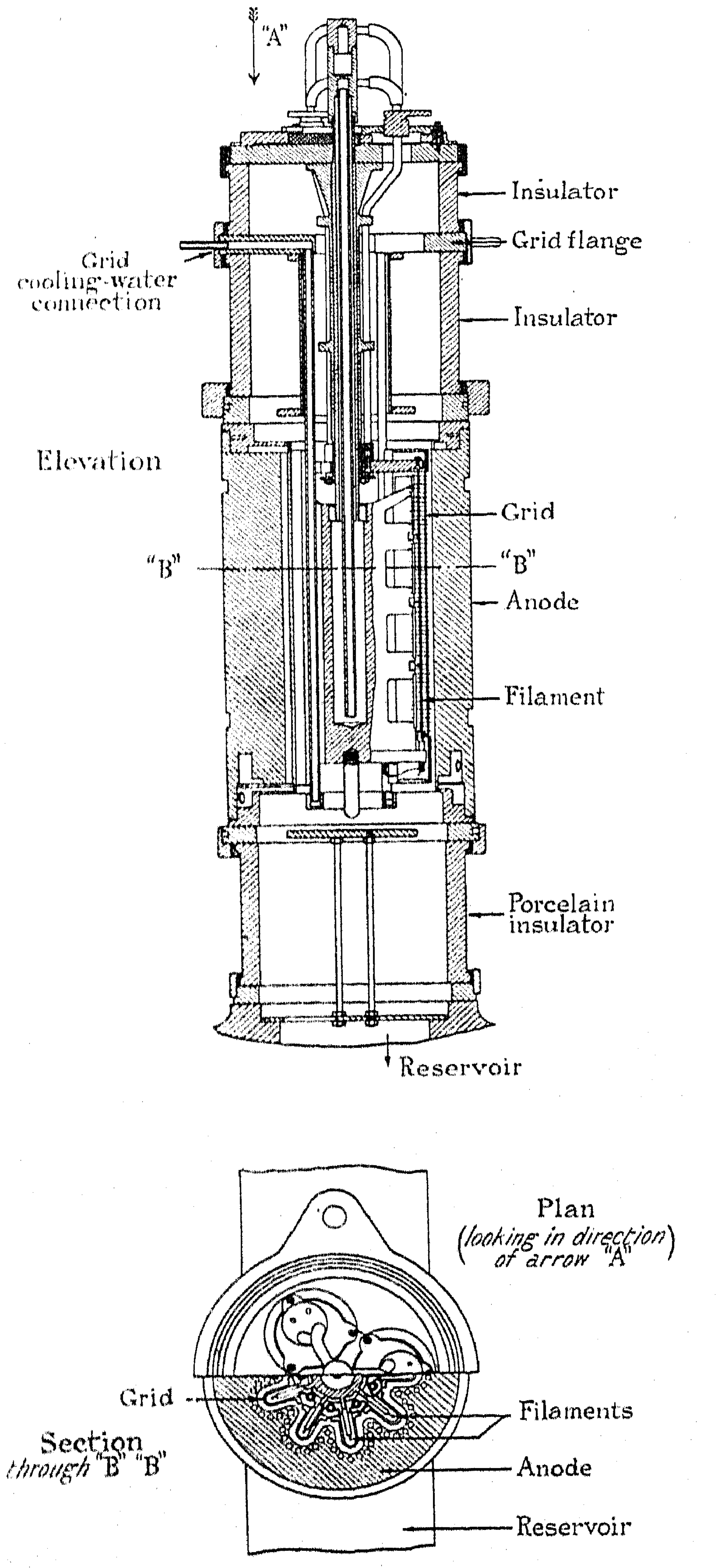

FIG 30.—Assembly of 500-kW demountable valve.

The grid and filament assemblies are shown in Fig. 30. The grid structure is water-cooled and is made of copper. The molybdenum grid elements are of flat horseshoe shape, clamped to their respective copper supports and held rigid by longitudinal molybdenum rods.

The filament system is 3-phase star-connected. The filaments are straight tungsten wires, the bottom ends of each being connected to the neutral.

The anode is fitted with 3 hydraulic jacks which are used to lift the grid and filament assemblies clear of the anode and also serve to position these electrodes when the valve is reassembled.

The pumping system is arranged in four stages, viz.

(1) Mechanical backing pump.

(2) One oil-vapour pump (high backing pressure, low-speed).

(3) Two oil-vapour pumps in parallel (high-speed).

(4) Ten oil-vapour pumps in two groups of five each group, exhausting into one pump of stage 3 (high-speed).

The fine side of the last ten pumps is the working vacuum for the valve. There are two vacuum reservoirs in the pumping system to give a greater cubic capacity of vacuum. These serve the purpose of keeping a high degree of vacuum longer under bad conditions and also act as cushions for the pumps in the event of a sudden large evolution of gas during the process of conditioning.

Should the mechanical pump or the driving motor fail, it is possible to keep the valve in operation for several hours by using the low pressure in the reservoir as the backing pressure to the condensation pumps.

The factor of primary importance in the pumping system is the special oil known as " Apiezon " used in the vapour pump, the production of which has followed from research work in the production of oil distillates carried out in the laboratories of Metropolitan-Vickers Electrical Co. The properties of this oil are such that its rate of evaporation is exceedingly low at normal temperatures and the required degree of vacuum for operating a thermionic valve can be obtained without resort to cooling with liquid air, as in the case of mercury vapour, by reason of the low vapour pressure of the oil.*

The temperature of the cooling water used at Rugby is about 20° C.

Tests at Rugby.

Prior to the tests on the 500-kW valve a demountable valve of approximately 25-kW input had been in service at Rugby for some time and had proved sufficiently reliable to justify a full-scale experiment on the larger type.

Arrangements were made to connect the large valve as an alternative to the final amplifier in the main (GBR) telegraph transmitter.† This is operated with 54 water-cooled glass valves in parallel, and an input of about 560 kW is required for the normal aerial current.

The preceding amplifier stage of this transmitter is 50 kW. This stage was coupled to the 500-kW demountable valve for the tests with the output to the main aerial system.

The electrical supplies available were those normally used for this transmitter.

A few typical readings taken on the preliminary tests are given in Table 3, but it should be understood that these results are from short experimental trials.

The filament voltage supply is at 18–19 volts, the current being 160 amperes per phase and the total consumption 9 kW.

So far as experience indicates at present, the schedule for initially evacuating the valve is:—

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* C. R. BURCH: "Some Experiments on Vacuum Distillation," *Proceedings of the Royal Society*, 1931, vol. 123, p. 271.

† E. H. SHAUGHNESSY: "The Rugby Radio Station," *Journal I.E.E.*, 1926 vol. 64, p. 683.

(1) Start and run backing pump for 45 minutes.

(2) Start 2nd-stage coarse vapour pump and run for 15 minutes.

(3) Start two 3rd-stage high-speed vapour pumps and run for 15 minutes.

(4) Start ten 4th-stage high-speed vapour pumps and run for 15 minutes.

Total pumping time 90 minutes.

TABLE 3.

v_a	i_a	i_{ae}	Input	Frequency
volts	amps.		kW	kilocycles/sec.
8 000	43·9	585	351	16
8 500	47·5	650	404	16
8 750	51·0	665	446	16
8 800	49·0	670	430	16
9 150	57·0	710	521	16

After the completion of the work of erecting on site it was necessary to condition the valve to remove accumulated dirt and gas from the electrodes. The work of conditioning consisted in the application of potentials between grid and filament and between anode and filament, and in the dissipation of high powers in the grid and anode. At intervals during this conditioning period oscillation tests were made on the valve. The valve was opened up many times during the test but the extra conditioning necessary due to opening up to atmosphere was invariably found to be negligible. A small amount of surface gas was always absorbed by the electrodes but this was removed in the first few minutes of conditioning.

Several improvements and modifications have suggested themselves as the result of the preliminary trials, and prolonged tests are now to be carried out. The results are definitely indicative of a very pronounced advance in valve technique. I think that an account of the research work leading to the development and details of the performance would form an interesting paper for the Section, and I hope that it will shortly be forthcoming.

ACKNOWLEDGMENTS.

I could not have undertaken the preparation of this address without the collaboration of many of my colleagues, and in fact the co-operation has been such that it is difficult to specify individuals.

It has been a great pleasure to me to put on record the results of the work carried out at the laboratory at Dollis Hill, and at Colney, Rugby, etc., and to all those who have been concerned in these investigations and developments my sincere thanks are tendered. I must, however, particularly refer to Mr. Nancarrow who, in addition to other assistance, has carefully checked the data on measurements.

My acknowledgments are also due to Messrs. Metropolitan-Vickers Electrical Co., Ltd., for the details they have furnished of the construction of the demountable valve.

METER AND INSTRUMENT SECTION: CHAIRMAN'S ADDRESS.

By F. C. KNOWLES, Associate Member.

"THE GROWTH OF ELECTRICAL MEASUREMENT FROM ITS COMMENCEMENT."

(*Address delivered* 6*th November*, 1931.)

I am deeply sensible of the honour this Section has conferred upon me in electing me its chairman for the coming Session. I accept it as a compliment to the branch of the industry which I represent, and I will endeavour to maintain the high standard set by my predecessors.

This Section now embarks on its fourth year, having already established a fine record by its papers and discussions. It has attracted many of our leading specialists in electrical measurement to read papers, and has given opportunity to all to exchange knowledge and experiences not only during the formal meetings but in the social intervals which have proved so valuable in assisting that spirit of camaraderie which permeates the Section. I am sure that each one of us is proud of what we have achieved, but there is still much to be accomplished. There are very many in the Institution who are eligible for membership of this Section and are not yet enrolled. Mr. Fawssett stressed this point in his Chairman's Address last year and has since devoted much time to increasing our membership, especially in the provinces. It is very gratifying to note that since that address the membership of the Section has increased by 50 per cent, making a total of about 420.

The membership is now much more representative not only of the various aspects of electrical measurement but also of the geographical distribution of the members of the Institution. We have now five members from the provinces on the Committee, whereas two years ago there was only one; this growth of representation is very welcome to those of us who reside within easy reach of London.

To enable this Section to fulfil its function in relation to the other interests in the Institution it seems highly desirable that from time to time papers dealing with some aspect of electrical measurement should be read and discussed at the Local Centres, and it is gratifying to learn that some Centres have already fallen in with this suggestion and that others are endeavouring to follow suit. This will not only give the members of this Section resident in a given Local Centre an opportunity to take part in a meeting of special interest to themselves, but will also enable them to persuade those of their friends who are eligible to join this Section. It is my intention, as far as possible, to be present at these meetings at the Local Centres.

Before leaving matters relating to our internal affairs I should like to touch on the question of papers to be read before this Section. There is a great deal of original work which has been done and which has never been published although the results are daily applied, either in the laboratory, workshop or the supply industry, and much of this information could be available "to promote the general advancement of electrical science," without sacrificing special interests. Most of the early experimenters, upon whose labours our industry is founded, did not spare themselves in any way or consider their material welfare, but hastened to make public full details of their discoveries for the benefit of all mankind. Such generosity made for progress and, while to-day conditions have changed, there is still need for more of that spirit of the free interchange of knowledge and the practical application of the ideals which prompted Faraday, Hughes and many others whose names are lost but whose work lives.

We are all busy men but I would ask all who can to make sacrifices to prepare and present papers. I would also appeal to those in authority to take a broad view and release information, thus giving to the Institution the opportunity of presenting to the world discoveries and improvements so that the credit may redound to British electrical engineering. We want this Section to be the channel for concise and, as far as possible, complete publication of new matter relating to electrical measurement and allied subjects.

As a student I remember seeing a picture, I think it was in the Tate Gallery at Millbank, entitled "Measurement is Science." It represented a professor—the personification of accuracy—standing before the skeleton of a stork, his measure in hand, taking dimensions of the various joints, possibly to prove some theory relating to evolution. Such measurement was only possible when the activity of the bird had ceased, and only revealed the more or less remote past. To-day we electrical engineers have to deal with measurement not as science in the dead sense but as a living and ever-changing reality. Such measurement must be applied science, based on sure and certain knowledge capable of indicating the present and, if possible, showing the trend in the immediate future. To-day measurement is control or affords the information so that control can be effected with promptness and precision, and thus at once supplies the key to efficiency and economy. This is the basis of the great interlinking of electrical supplies now going on throughout the world, to which I will refer again later.

In the majority of cases no single measurement is of value by itself but must be taken in relation to past determinations, and so enable the discriminating observer to predict with reasonable certainty the near future. A single example of this is found in such a case as the systematic recording of the insulation resistance of a cable or piece of electrical apparatus. The values for a time may be reasonably steady, but as time goes on the values fall at first slowly, indicating incipient weakness, and then more rapidly, showing impending failure with possible shut-down of plant, involving loss of output. Such information enables the engineer to cope with the conditions at a convenient time without serious dislocation of the service he is giving.

To-day, surrounded as we are by such a galaxy of ingenious instruments, some of them measuring quantities not even contemplated fifty years ago, it is difficult to appreciate that the early pioneers in our industry had no easy way of measuring the value even of a direct current. In describing one of his experiments Hughes mentions that his battery was "working vigorously," but he had no ammeter and was only able to judge the current passing round his circuit by the results he obtained from his microphone or other apparatus with which he was experimenting. The historical side of measurement has always appealed to me, and when contemplating the preparation of this address I spent some time delving into the past and found it not only of great technical value but of such absorbing interest that I thought I would trace for you the growth of electrical measurement from its early beginnings and show how within the past fifty years all the direct reading instruments have been developed. Such historical treatment of the subject is not now necessary, as many of you had the opportunity of seeing recently, at the Faraday Centenary Exhibition in the Albert Hall, the finest historical collection of electrical measuring apparatus ever brought together. This was superbly arranged and showed how from the simple coils and magnets of a hundred years ago the complex instruments of to-day have been evolved.

It was very interesting to see that most of the inventors during the past fifty years have been members of this Institution, and would doubtless have been members of the Meter and Instrument Section if this had been in existence in those days. There is one to whom I would particularly refer, and that is Prof. W. E. Ayrton, who was President of this Institution in 1892. He was one of the first to realize that an instrument should be direct-reading. To-day we are so accustomed to seeing the scale on an ammeter marked definitely in amperes that it is difficult to put ourselves in the position of those who in the early days had current meters with degree scales which were supplied with a curve to interpolate the readings, or had a series of constants to apply—involving skill in obtaining the result and delay in applying it. Ayrton, with whom was often associated that other great and genial President of this Institution, Prof. J. Perry, invented in 1881—fifty years ago—a permanent-magnet voltmeter which consisted of a coil fixed between the poles of the magnet so that the flux of the coil was at right angles to that of the magnet. Pivoted in the coil, and hence between the poles of the magnet, was a small piece of soft iron on the axle of which was the pointer which indicated the applied pressure on a scale calibrated direct in volts. This type of instrument was also made as an ammeter, and many of you may remember seeing such an instrument fitted with a series-parallel commutator switch to obtain several ranges. Simple ammeters constructed on the principle demonstrated by Ayrton are fitted in most motor cars to-day. Little did Ayrton think that within a short span of years some half a million people in all parts of the world would daily look to his invention to help them to control their portable power stations.

In 1881 Ayrton* also made this type of instrument with voltage and current coils as a resistance indicator. This is as far as I have been able to trace the first ohmmeter, but very few of them appear to have been made.

Although Ayrton devoted a great deal of his abilities to the instrument side of measurement it is very interesting to find it stated by a well-known American authority on integrating meters that Dr. Siemens and Prof. Ayrton working together have had ascribed to them the credit of the first "commutator motor meter." Ayrton is also generally credited with conceiving the idea of controlling the speed of a motor meter by utilizing the Foucault principle of a damping disc reacting with permanent magnets. The joint conceptions of Siemens and Ayrton were first reduced to a really successful commercial basis by Prof. Elihu Thomson in 1888. Here again the ingenuity of Ayrton is used by millions throughout the world, but most of these are unaware of it.

My object in dwelling for a short space on the contributions of Ayrton to the science and practice of electrical measurement is to do honour to one of our Past Presidents, whose work is used but whose name is in danger of being forgotten, and also to show how from very small beginnings a world-wide service can be given to the community.

Whatever romance and charm the past may have, it is the present which demands our interest and attention, and so I propose to review some of the present-day applications of instruments to industry. There has arisen during recent years a demand for remote indication to be given at one central position of a number of quantities originating at different places. The distance of transmission of these indications may vary considerably, and the following examples will help to explain the problem.

Power station engineers find it increasingly necessary to keep the boiler house informed of the total load on the station. A system for summing the total power of the station is installed and the indications of the summation wattmeter are repeated in the boiler house, often by very large indicators, and by smaller indicators in other parts of the generating station, including the engineer's office. In such an equipment the distance of transmission may be only a few hundred feet. An example of this will be found at the Barking station of the County of London Electric Supply Co.

Also, with the advent of outdoor substations and switch rooms detached from the generating station, a modification of the previous equipment is installed with the addition of remote transformer tapping indicators to show at the switchboard the position of any of the tap-changing gear on the individual transformers.

Again, the combination of a number of power stations each feeding into the system of a local supply authority calls for an extension of the method employed at a single power station. Repetition of the total output and, in some cases, the steam pressure to a central control office must be made by pilot wires—often several miles long—usually owned and laid by the supply authority in their own cable ducts. At the central control office the total electrical output of each station is indicated and the summated total of the whole system is given on a single indicator. Such an arrangement is employed by the London Power Co. at their control room at Horseferry Road.

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* *Journal of the Society of Telegraph Engineers and Electricians*, 1882, vol. 11, p. 268.

Further, in some cases where long-distance transmission of indication is required—possibly hundreds of miles—use is made of the existing lines of the telephone authority. Where these are straight-through metallic circuits no arrangements other than those already mentioned have to be made. Sometimes, however, repeater stations are introduced along the lines, and then it is necessary to adopt a special impulse or speech-frequency current to pass through these circuits to give indication at the further end. Various examples of this will be found in Central Electricity Board schemes when these are completed.

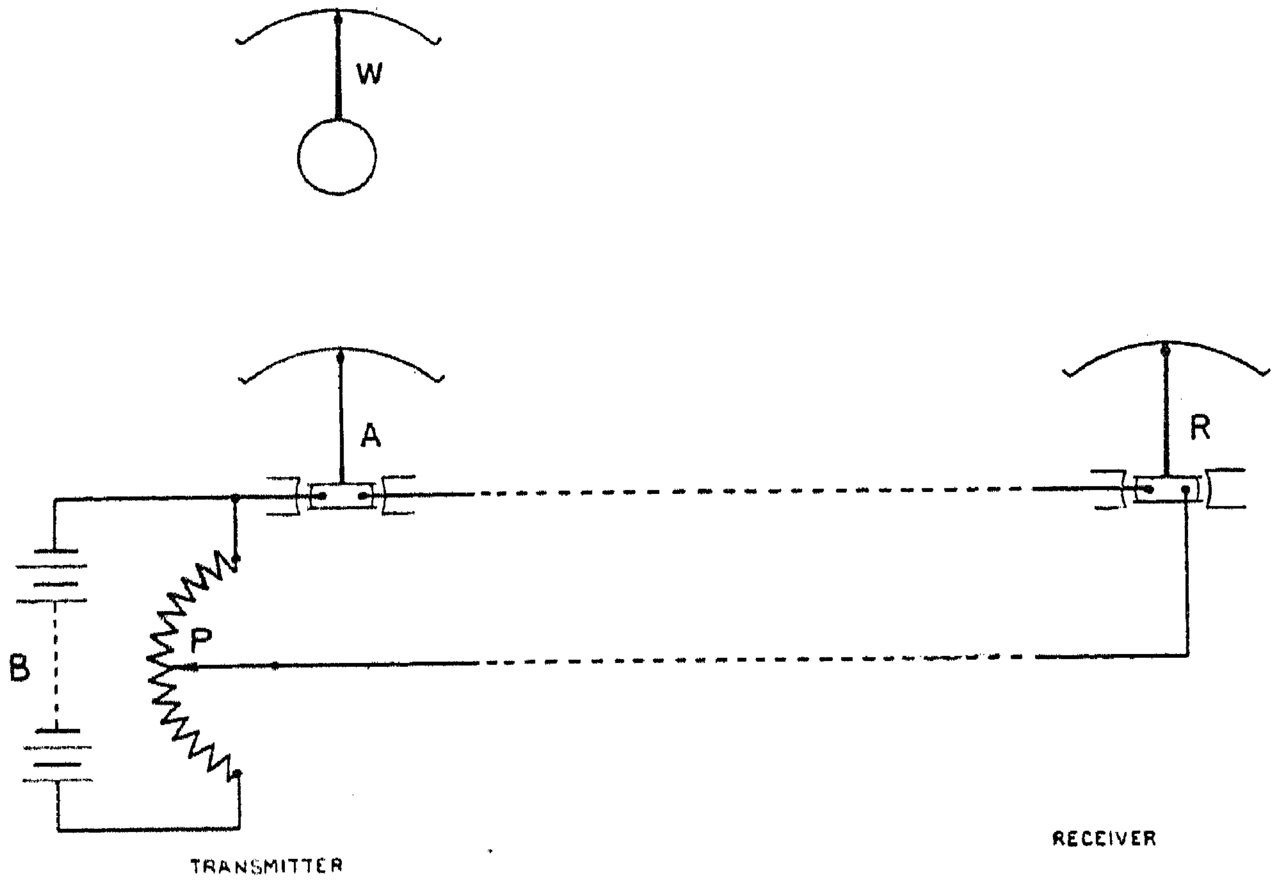

FIG. 1.

It may be of interest to glance at some methods of remote indication. A very simple form consists of a hand-operated resistance connected across the supply, feeding current to two instruments in series, each being identical and scaled appropriate to the information to be transmitted. If it is desired in a power station with such a system to transmit from the switchboard to the boiler house the total load of the station, the switchboard operator reads the total-load wattmeter W and sets the adjustable resistance P so that the indication on his "setting" instrument A corresponds to that of the wattmeter W, and then the boiler house instrument R will repeat this indication (see Fig. 1). Many variations of this simple arrangement have been erected by operating engineers to suit their particular requirements, but they all introduce the human link and so are not automatic.

Where the quantity to be repeated can be translated into mechanical motion with sufficient power, automatic indication can be obtained by causing this motion to operate the adjustable resistance. While this will give an automatic repetition the accuracy of the indications so obtained will be dependent on the voltage of supply. To overcome this it is necessary to provide a constant pressure of a predetermined value. Various methods have been employed, such as the use of a small voltage-regulator in the supply circuit, either of the relay type which cuts resistance in or out, or of the hot iron-wire type which was used many years ago in the Nernst lamp, the resistance of which alters very considerably with small variations in the supply voltage.

As an alternative to keeping the pressure constant, attention has been directed to the indicating instruments. Auxiliary windings, energized from the supply voltage, have been introduced to compensate effectively for a variation in voltage of ± 50 per cent.

In addition to voltage variation there is another factor which may affect the accuracy of the indications, viz. the change in resistance of the pilots due to changes in temperature or any other cause. This may be very considerable on long overhead lines.

A system due to Midworth* has been developed which, while giving continuous remote indication automatically, compensates both for variations in the supply voltage and changes of resistance in the connecting lines (see Fig. 2). It operates on direct current and requires two lines between the remote receiving instrument and the transmitter, in which is incorporated the originating movement the indications of which are to be repeated. The receiving instrument or instruments, which are moving-coil milliammeters, are in series with each other, the lines and a similar milliammeter in the transmitter, the whole being connected across a motor-controlled potentiometer in the transmitter. The originating movement W in the transmitter is provided with an arm mounted co-axially with, but independent of, the control milliammeter A, and a contact on the one floats freely between two contacts on the other. Any change in position of the originating movement causes contact to be made on one or other side, thereby starting the motor M in one or other direction, altering the position of the tapping point P and thus the current in the control milliammeter A. The pointer of this milliammeter follows the motion of the originating movement until the system is again in equilibrium, and the receiving instrument R or instruments in series with it correspondingly follow the motion. Any variation in the supply voltage or change in the resistance of the circuit has the effect of altering the current in the receiver circuit, which causes the motor appropriately to alter the

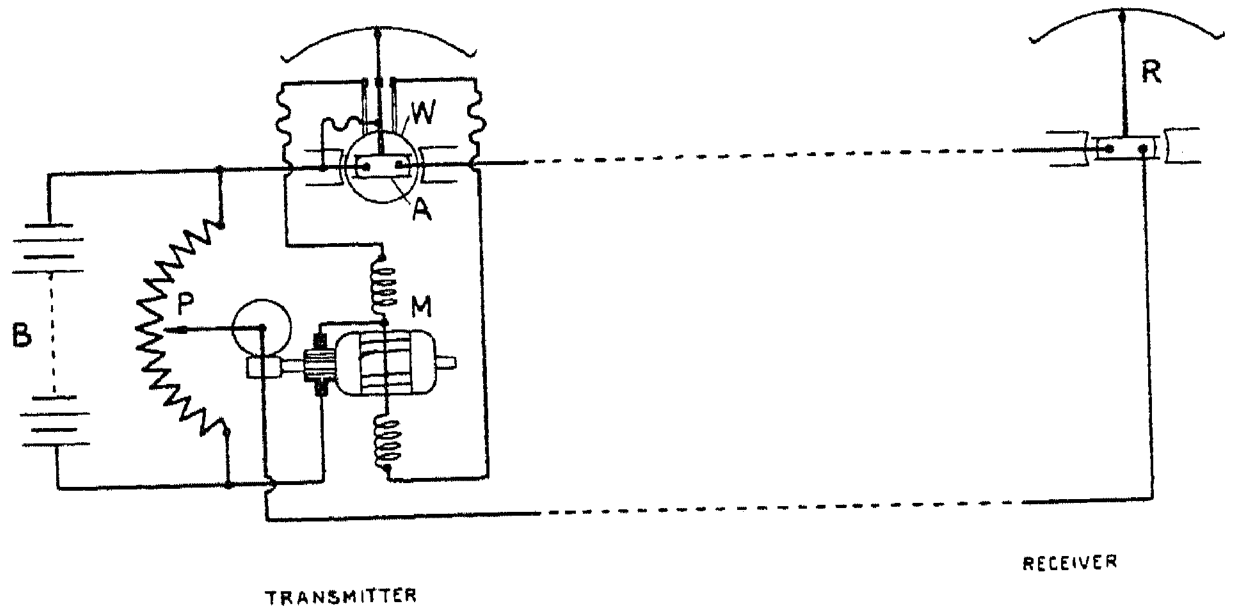

FIG. 2.

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* British Patent No. 263012.

potentiometer tapping point to restore the current through the receivers to their original value. This simple system is applicable to the repetition of any quantity or position which is originated by an angular deflection, without imposing any load on the originating movement, and can be transmitted to any distance.

A remote indication system (see Fig. 3) has been evolved by Leeson, Harle and Lambert,* based on the idea of fitting to the instrument the readings of which are to be repeated an additional pointer capable of being moved over the instrument scale by a constant-speed motor. At the remote position where the indications are required an indicator is fitted which has two pointers, one which can be moved by a constant-speed motor, and another which is pushed forward by the motor-driven pointer. The motors at each end must run at the same speed, and, if they are on systems having the same controlled frequency, a.c. synchronous motors can be used. In principle the method of operation is for the engineer at the remote position to press a contact key G corresponding to the instrument the reading of which he desires to know. The indicating and motor-operated pointers R and Q at his end will be at the last spot reading taken, and zero, respectively, and at the instrument end the motor-driven pointer P will be at zero, while the instrument pointer W will be at some position on the scale. The depression of the key G will complete circuits clutching-in the motors M and N at both ends simultaneously, and they will continue to run until the instrument motor M has moved the additional pointer P so that it touches the indicating instrument pointer W. The motor clutch circuit will immediately be broken and the indicating pointer R on the instrument before the engineer will be clamped in position, giving the scale reading corresponding to the originating instrument W. The motor-driven pointers P and Q at each end will return to their respective zeros to await a repetition of this process when desired.

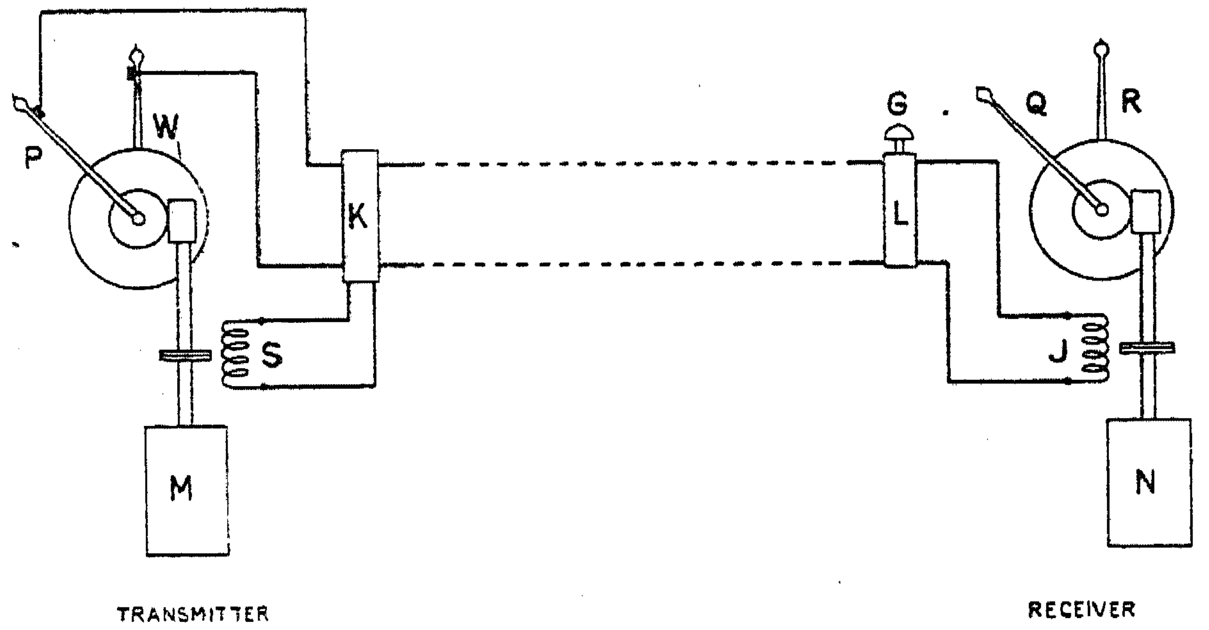

FIG. 3.

Fig. 3 was merely a sketch showing the principle, but Fig. 4 shows in more detail some of the units required and their function. Let us follow the operations. At the receiver end the key G is depressed. This energizes coil H, thereby releasing pointer R which falls towards Q due to its control spring. At the same time the coil J clutches-in the motor N which drives arm Q up the scale from zero, and simultaneously plunger switch D completes the circuit to the pilot lines, enabling generator F_2 to transmit a current of suitable frequency to the transmitter. This current passes to K, which is a receiver tuned to the frequency of generator F_2. The coil S is thus energized and clutches-in motor M, which drives pointer P until it makes contact with pointer W. This completes the circuit for the generator F_1, the frequency of which differs from that of F_2 and sends through the pilot lines a current which is received by L tuned to the frequency of F_1. Immediately switch C opens, de-energizes coils H and J, and thus clamps the pointer R, stops the progression of Q and opens switch D. P and Q are then returned to their respective zeros, motor M has been de-clutched, and switch C is reinstated, and the whole equipment is ready for the next "spot" reading to be taken.

This system can be amplified in many ways. For example, it can be made to give continuous indications by a form of follow-up contact, but as there is a tendency for the errors to become cumulative a reversion to zero is periodically made.

The inventors claim that the transmission of the starting and stopping signals may be effected by means of high-frequency currents with wired or wireless or wired-wireless transmission either by direct transmission of such currents or by modulating a carrier-wave system at suitable frequencies.

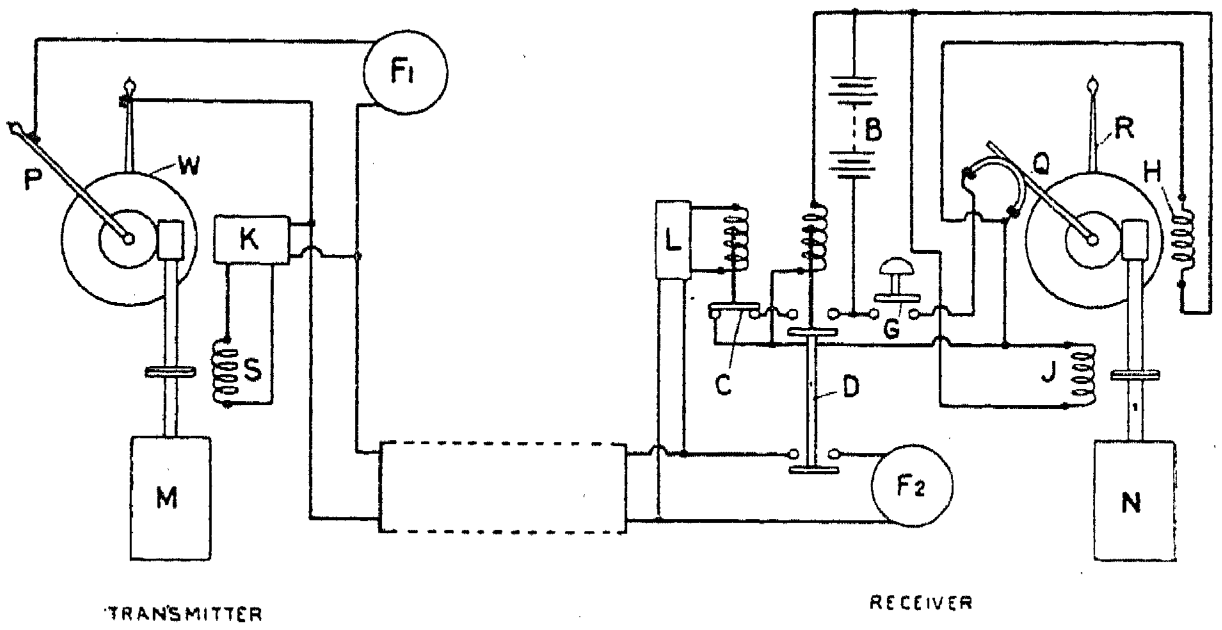

FIG. 4.

There has been developed in America a system giving remote indication of a mechanical motion. This is based on the self-synchronizing of induction regulators which are of a special form. The transmitter and receiver are similar elements, each having a rotor and a stator. The rotor, which is usually shuttle-shaped, carries a single winding and is energized from a single-phase a.c. supply, all the rotors being connected in parallel. The stator, which is usually of ring construction, is provided with a 3-phase form of star-connected winding, the three ends being brought out and connected in parallel with all the other stators. This arrangement is used principally for transmitting mechanical positions or orders, but if very lightly constructed it may be applied to remote indication. It usually requires five connecting lines between the transmitter and receiver, but if the same supply is available at each end three lines only are required. In this event the supplies at each end must be exactly in phase with one another.

A system developed in Germany which has a limited application is used for the repetition of wattmeter indications either singly or summated. It consists of an integrating meter driving a small d.c. generator, the e.m.f. developed being directly proportional to the speed and hence to the kilowatts. The receiver is a moving-coil millivoltmeter connected to the d.c. generator by two lines, and when it is desired to sum several supplies the d.c. generators are connected in series.

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* British Patent No. 344827.

A very ingenious system of remote indication has been devised and put into operation by our immediate past-chairman, Mr. Fawssett. The principle is shown in Fig. 5, where it is seen applied to the indication at a distance of a 3-phase balanced load. In one line are connected two identical special current transformers CT_1 and CT_2 energizing separate heater elements H_1 and H_2. These are so arranged that when the heaters are connected in series the instantaneous polarities of the ends of the heater are opposed to one another. Through the heaters is passed an additional current which is proportional to the phase voltage obtained from a voltage transformer T. Thermo-couples TC_1 and TC_2, connected in opposition, impress an e.m.f. on a pair of pilot wires at the remote end of which is a sensitive moving-coil millivoltmeter R calibrated in kilowatts.

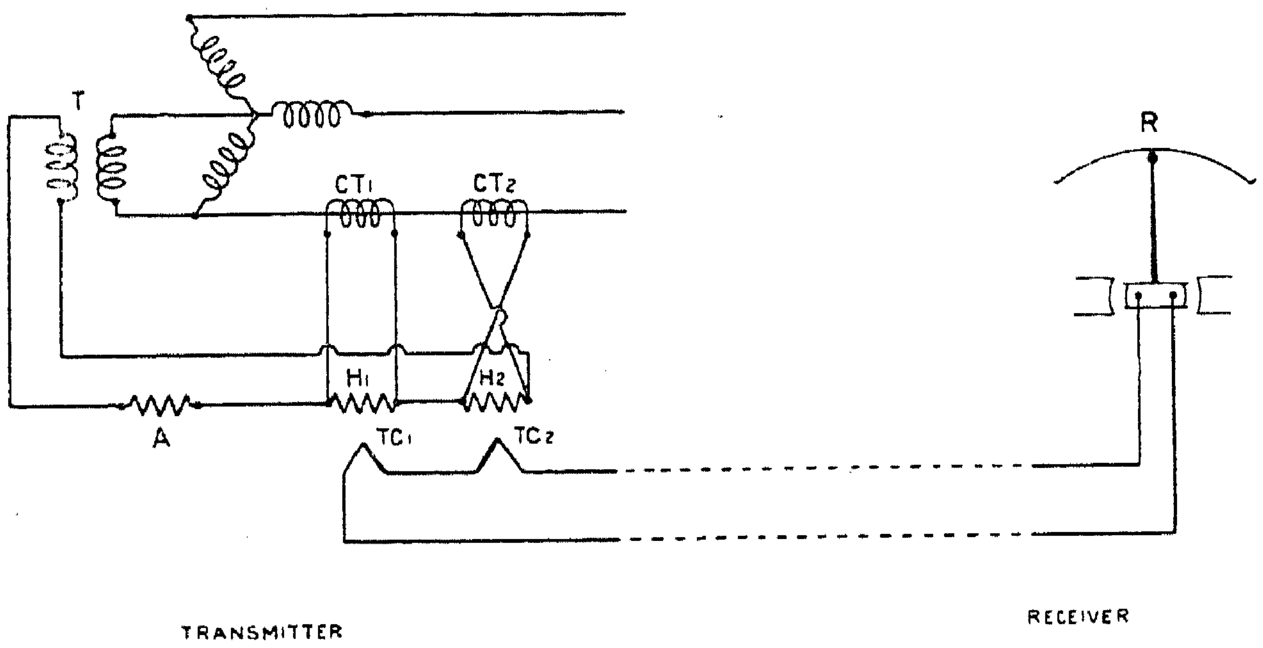

FIG. 5.

That the principle is sound may be proved mathematically as follows:—

Let e' = instantaneous e.m.f. of thermo-couples.
e = instantaneous voltage, proportional to phase voltage.
i = instantaneous current, proportional to line current.

Then
$$e' = k\left\{(e+i)^2 - (e-i)^2\right\}$$
$$e' = k \times 4ei$$

If $E_{eff.}$ = effective e.m.f. for a half-cycle

then
$$E_{eff.} = \frac{4k}{\pi}\int_0^{\pi} ei\,dt = 4k\,EI\cos\phi$$

Thus the resultant e.m.f. developed by the thermo-couples is directly proportional to the power of the originating circuit.

It almost seems that such an intriguing scheme could be modified to measure that elusive quantity "kVA." Many inventors and scientists have been working on the problem of kVA measurement, and some claim to have solved it by the use of metallic rectifiers in the ordinary pressure and current circuits of a wattmeter. Unfortunately the solution is not quite so simple as this, but the work of Baker* and Finnis has enabled the problem to be solved relatively easily within commercial limits of accuracy.

An ordinary double-element wattmeter is used and for a single-phase circuit the current windings are connected in series through a full-wave metal rectifier to the current transformer (see Fig. 6). The pressure circuits are each connected across the mains through metal rectifiers, but one has a non-inductive resistance while the other has a condenser. The effective currents through these pressure circuits are in quadrature with one another. The result is that the wattmeter reads the volt-amperes of the circuit, independent of power factor. This principle may be applied to any form of a.c. circuit. In the case of a 3-phase balanced load the quadrature pressure is obtained by connecting between one phase and neutral, while if the circuit is unbalanced triple-wound interlaced current coils may be used.

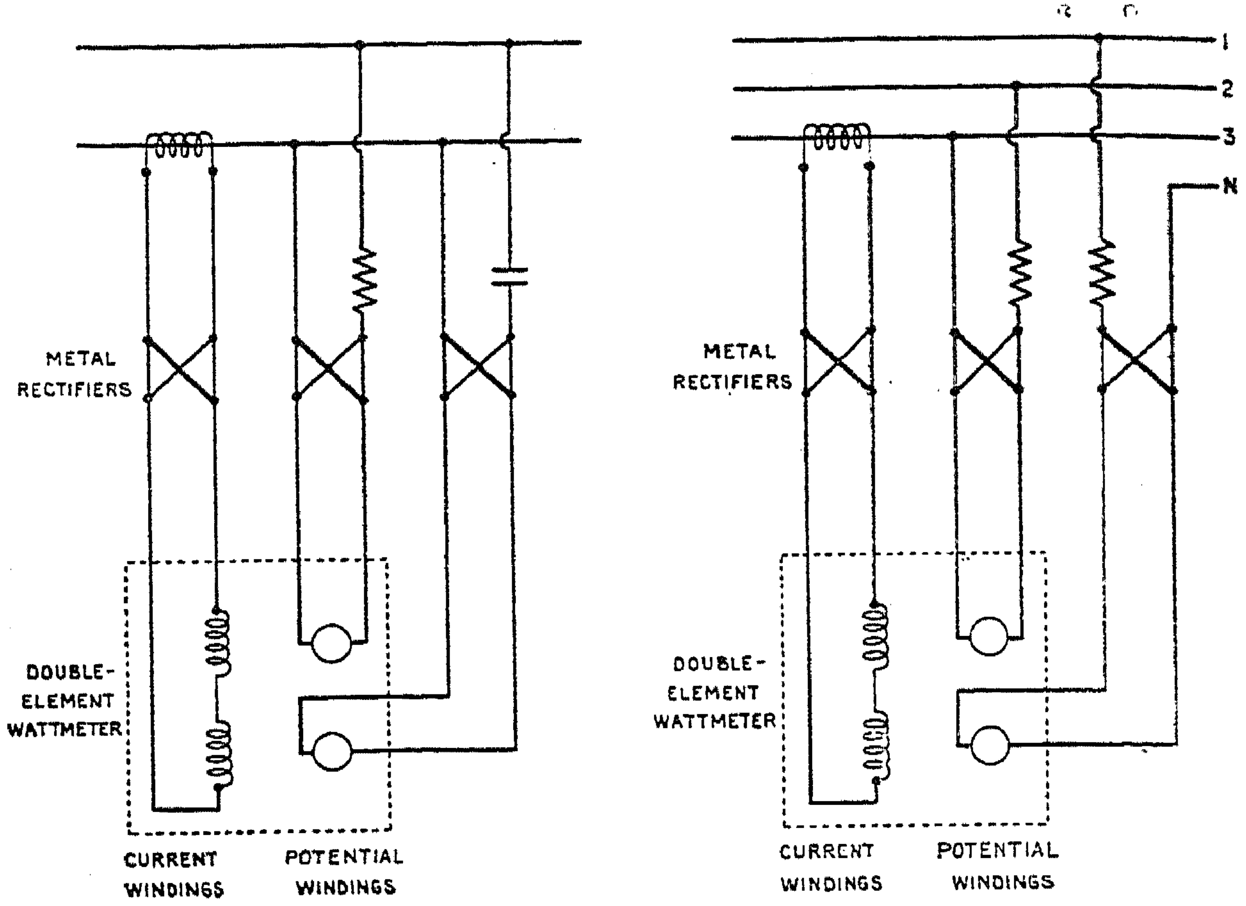

FIG. 6.

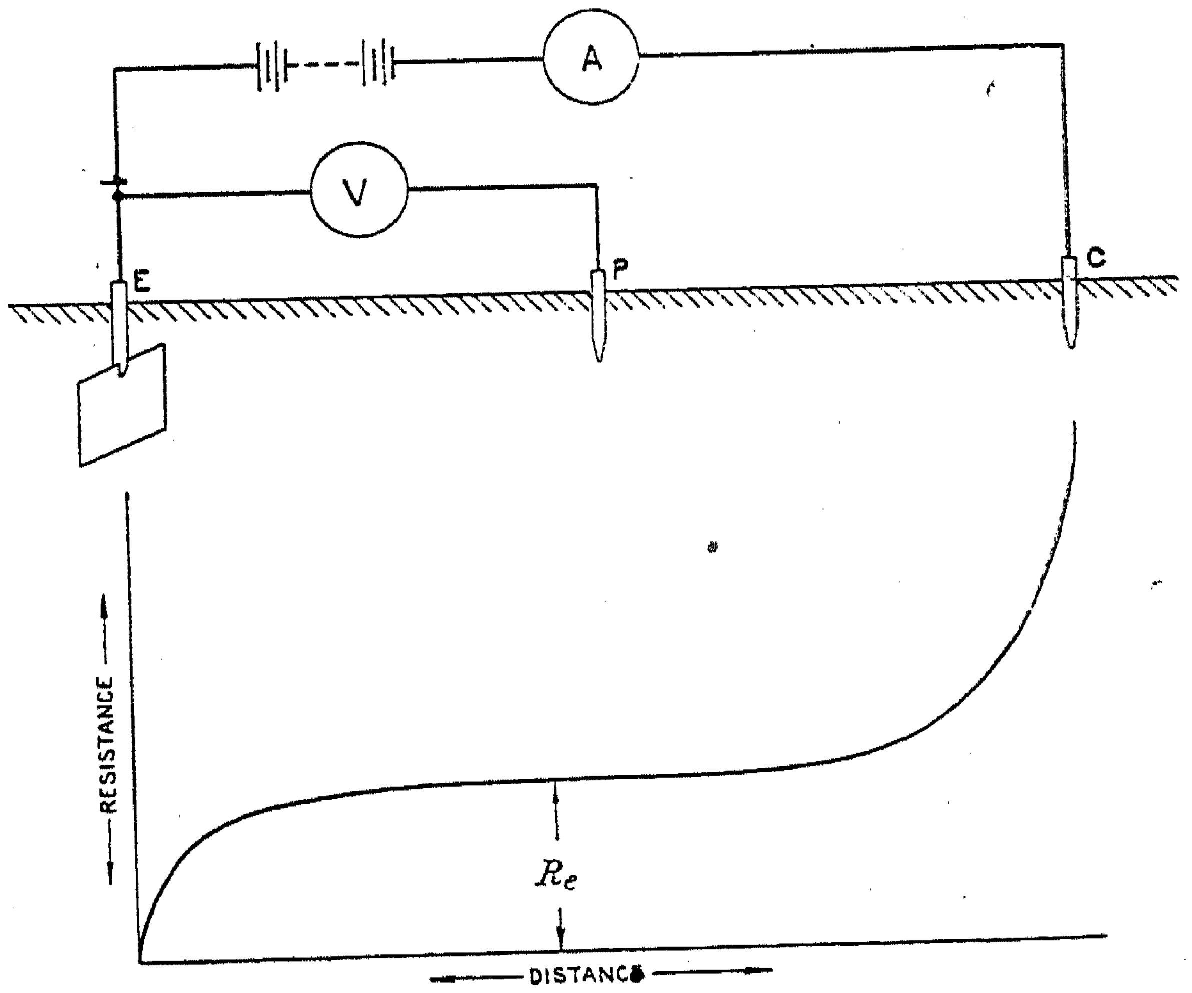

FIG. 7.

The development of overhead transmission lines has compelled engineers to give attention to the provision of adequate earthing of the towers, poles and other structures. Often, in the past, earth plates have been buried in the earth and forgotten. It has been assumed that they were of reasonably low resistance and thus would fill their function of protecting personnel and property. This has not always been the case and several instances of the tardy response of the protective relays have been due to the high resistance of the earth plates.

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* British Patent No. 357347.

Before examining the various instruments available, let us see what we mean by the resistance to earth of any metal body which is in contact with the earth. If a steady current be passed from an earth plate through the earth to an electrode driven in the earth, and if the potential-drop be measured successively on a line between them, it will be found that the potential will increase until the potential electrode is some distance from the earth plate, and then there will be practically no change in the potential-drop until the potential electrode is moved nearer to the fixed electrode, when the potential will again increase, rising rapidly as the fixed electrode is approached. This is shown in principle in Fig. 7, where E is the earth plate, P the potential electrode, C the current electrode, A an ammeter, and V a voltmeter. If the current is steady the potential-drop is directly proportional to the resistance and thus in the curve resistance is plotted against distance.

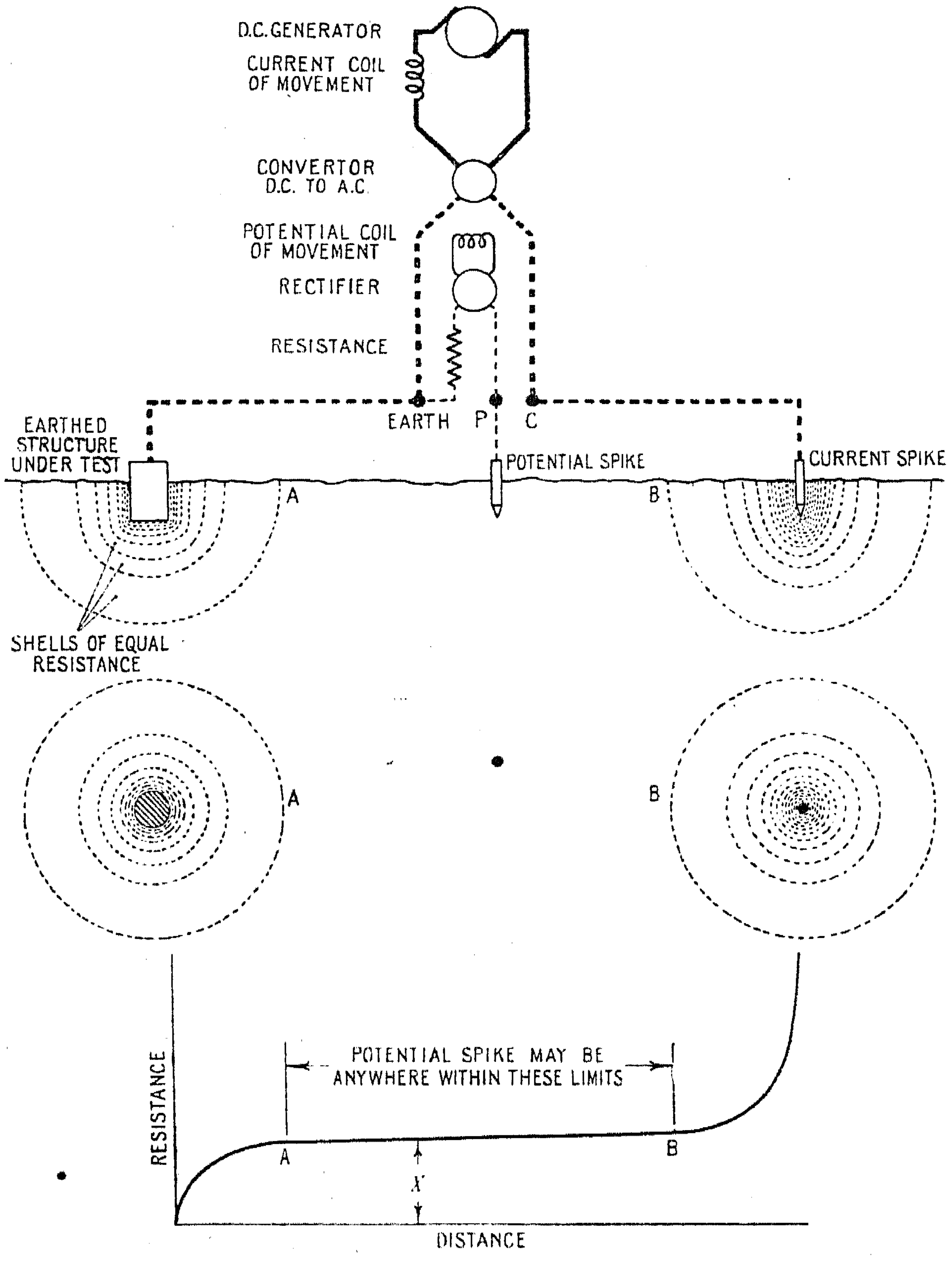

FIG. 8.

It will be apparent from the diagram that the resistance of the earth plate to the main body of the surrounding earth will be R_e. While this is quite simple in theory and also in practice where the earth plate is small, it should be remembered that if the earth being tested has a very distributed resistance, as would be the case with a large metal structure, the current electrode C will have to be placed at a considerable distance from the structure so that the resistance/distance curve will have practically a horizontal portion, indicating that as there is no appreciable change this is the true resistance of the structure to earth.

The majority of modern apparatus for earth measurements use an alternating testing current to overcome the errors due to polarization and electrolysis. A very ingenious instrument due to C. E. Perry* has been developed which combines all the advantages of a d.c. ohmmeter with the use of alternating current in the earth circuit. It may be considered as working on the fall-of-potential method described in Fig. 7, with the ammeter and voltmeter combined in one moving system, and a single pointer giving the resistance directly in ohms. The principle of construction is shown in Fig. 8. Current is supplied by a d.c. hand-driven generator and, after passing through the current coil of the ohmmeter, is changed into alternating current for the test by means of a current reverser. The potential-drop across the earth under test is picked up by the potential electrode P and rectified to direct current to actuate the ohmmeter potential coil.

The diagram indicates hypothetically the shells of resistance which surround any current-carrying metal structure in the earth. The plan view shows these resistance areas. The potential spike should be placed in a position which is outside these resistance areas. The curve in the lower portion of the figure illustrates graphically the change of resistance with distance, and shows that if the potential spike is placed in a position corresponding to the portion of the curve which is practically horizontal the value so obtained will be the true resistance of the earthed structure under test. Fig. 9 shows the details of construction.

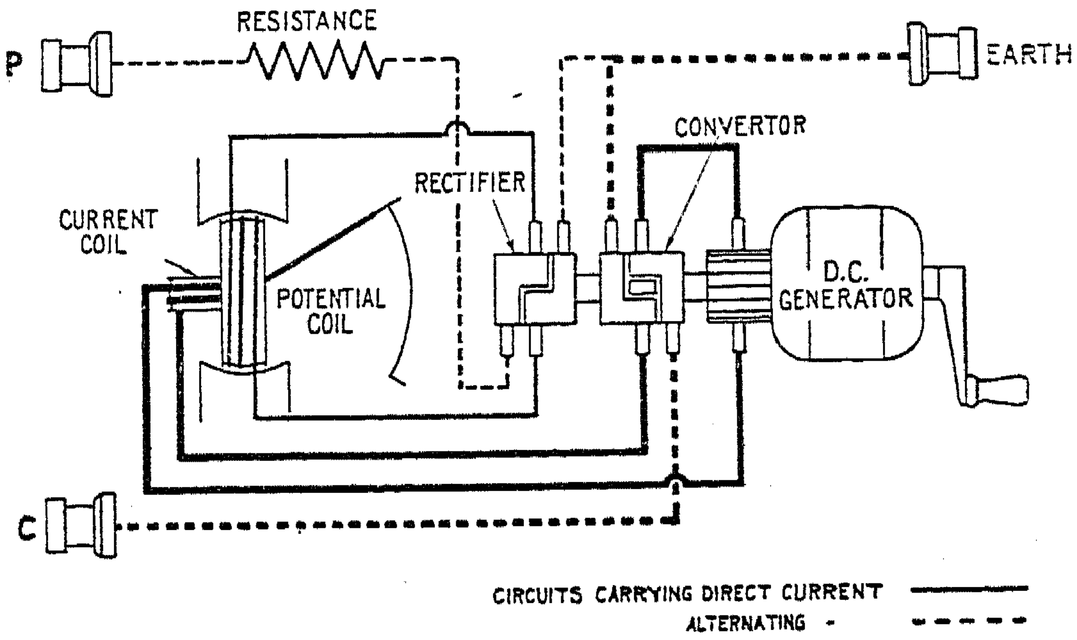

FIG. 9.

This type of instrument may also be used to determine the resistivity of the soil *in situ* and thus assist in the selection of a suitable location of earth plates from the electrical standpoint.

An instrument produced in Germany uses the fall-of-potential method combined with a form of a.c. bridge. Fig. 10 shows a diagram of connections of this apparatus. It consists of a hand-driven alternator developing current at about 35 cycles per sec., which it supplies through the primary of a transformer to the earth plate under test. An electrode C conveys the current back to the alternator through one of the fixed coils of the galvanometer G. The secondary of the transformer supplies current through an adjustable resistance R and produces a voltage-drop. This is balanced against the voltage-drop across the earth plate resistance picked up by the potential electrode P using the a.c. galvanometer G. The instrument is not direct-reading, it being necessary to obtain a balance on the galvanometer by adjusting the resistance before reading the scale.

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* British Patent No. 249615.

An instrument utilizing the Wheatstone bridge principle is in use in America. The testing current is obtained from a battery-operated buzzer, and a telephone is employed to indicate when balance is obtained. Two balance operations are necessary to obtain the result.

An instrument operating on quite a different principle from any of the above has been developed in this country. It comprises a hand-driven alternator which supplies current through an ammeter scaled in ohms to the primary of a transformer. The secondary of the transformer is connected to the earth plate under test and a good earth such as a water main. Assuming that the resistance of the water main to earth is negligible the instrument is direct-reading. Fig. 11 shows a diagram of connections.

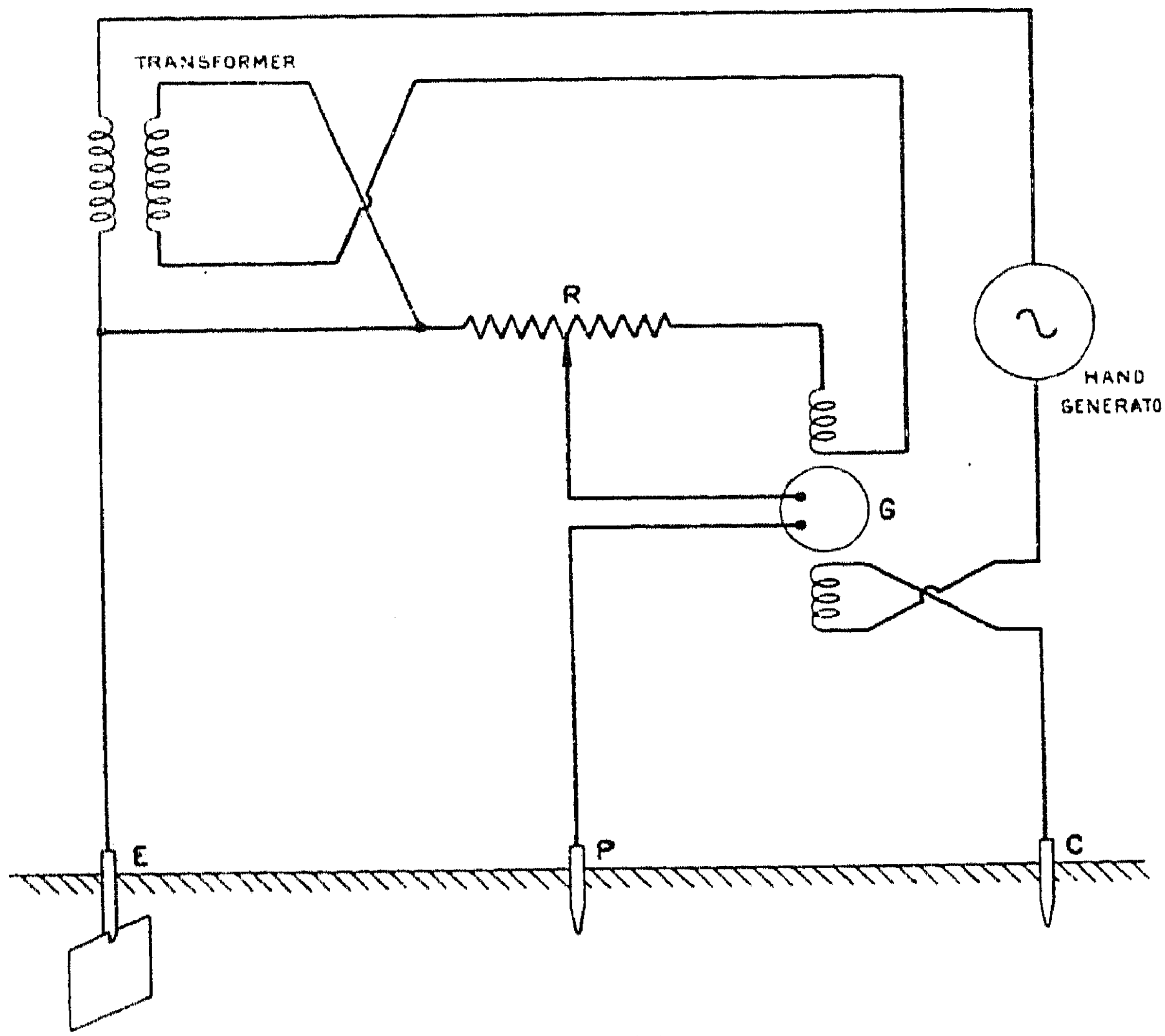

Fig. 10.

In addition to the above instruments, which are mainly intended for industrial testing, forms of a.c. potentiometers are used for some research investigations.

Industry to-day is faced with the necessity of producing goods and giving service of high standard and efficiency as economically as possible, and is realizing that this can only be obtained by knowledge of the conditions in each stage of production and immediately rectifying any departure from the schedule. Such information is increasingly being given by electrical instruments and the subsequent adjustment of processes by electrical control sometimes automatically operated from the instruments themselves. The application of electrical instruments to the measurement of physical quantities or conditions has resulted in the development of some very interesting apparatus, examples of which can be seen in the boiler house of a modern electricity power station. Here we find not only pyrometers giving the temperature of flue gases but instruments indicating the percentage of CO_2, CO and H_2 in the flue gases. The necessity for the measurement and control of these quantities is apparent when we remember that, of the heat available from the fuel supplied to a steam boiler, only about 60 per cent is employed in raising steam, and that 25 per cent of the remainder passes up the chimney in the hot flue-gases. A great deal of this inefficiency may be caused by an excess of air, and measurement of the CO_2 will show whether an excess of air is present. Usually the higher the CO_2 content of the flue gases the more economical is the combustion, while the reverse is the case with the CO and H_2. Both instruments used for these tests are forms of a Wheatstone bridge, the galvanometer of which is calibrated directly in the quantity being measured. Two arms of the bridge are platinum wires heated by a current, the other two arms being heated by the same current but exposed to the flue gases and, in the case of CO_2, thus losing heat, but in the case of CO and H_2 gaining heat by combustion. The bridge will be out of balance to an extent proportional to this heat exchange, and this will be shown on the indicator.

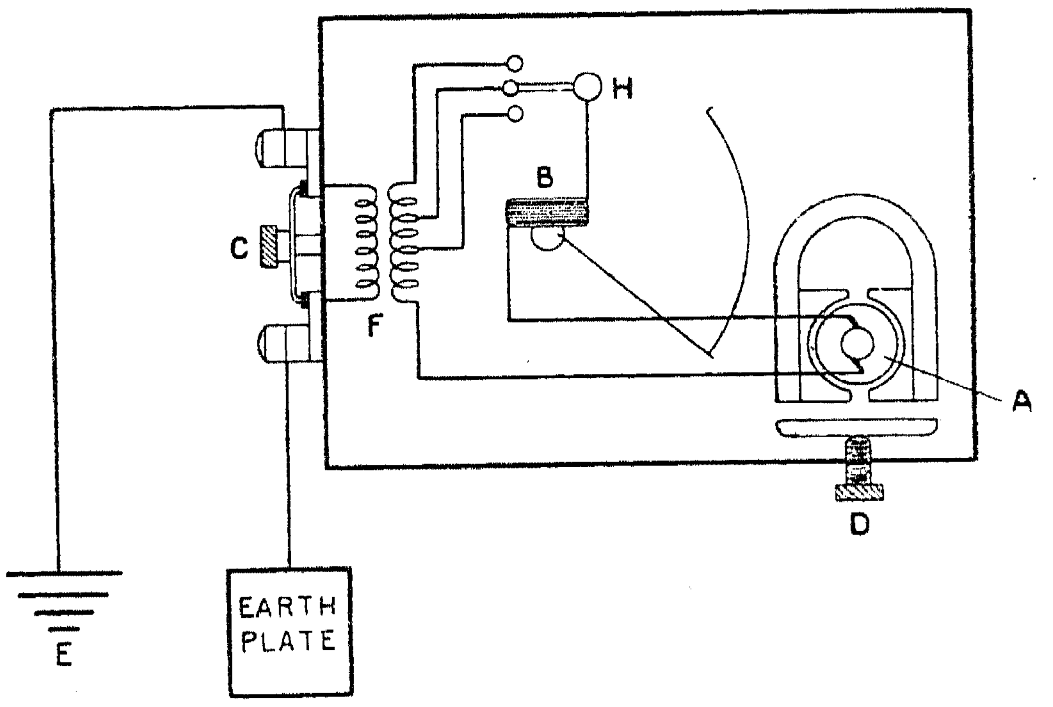

Fig. 11.

Instruments are also installed giving the smoke density of the flue gases, the principle of which is either a radiation pyrometer or a photo-electric cell. In both cases the instruments have scales shaded from white to black in definite grades as developed by Ringelmann.

The level of the water in the boilers and tanks is electrically indicated either by apparatus operating on the inductive bridge principle or a variable resistance as described earlier when considering remote indication.

The purity of the water in terms of electrical conductivity, whether feed, make-up or condensate, is indicated and recorded by an ohmmeter operating from a special water tube containing the test electrodes and an automatic compensator for temperature. The temperature coefficient is usually about 2·2 per cent per degree Centigrade. This apparatus not only informs the engineer of the condition of the water but also indicates incipient ingress of cooling water into the condensate, possibly caused by a cracked tube or leaky ferrule. The warning given enables repairs to be carried out at a convenient opportunity before the damage becomes serious.

The various instruments referred to are used by industry in numerous processes, and are often adapted to meet particular requirements, and it is here that the measurement engineer has to have not only a sound knowledge of his own science but a quick appreciation and understanding of the problem to be solved. The introduction of electric power into factories has familiarized manufacturers with electricity meters because as a result of their silent operations the bill is periodically presented. The tariffs based on a maximum demand are often the cause of the instrument specialist being called in to ease the financial burden caused by his meter confrère. Alarms are introduced giving notice of approaching peak loads, and time switches are fitted to cut in or out various circuits at known times of light or heavy loads. Chart-recording instruments are installed to show the time and duration of peak loads. The manufacturer, appreciating the saving effected on his power bill by knowing the conditions and controlling accordingly, often seeks the advice of the measurement engineer in relation to operations connected with the manufacture of his products. Many examples could be given, ranging from the production of motor-car parts being electrically scheduled to ensure an uniform rate of assembly to the remote indication and recording of the output of newspapers from printing machines.

In Germany and the United States of America measuring and control instruments have for many years past been much more widely used than in this country, but during the past few years the spirit of measurement has been extending here, owing in no small degree to the spread of the use of electricity. Electrical power has come into its own as the muscle and brawn of industry, and electrical measurement should seek to become the mind and brain.

At the outset of this address I set myself the task of directing your attention to some of the services given to-day by electrical instruments, and of necessity I have had to confine myself to a few with which I am more familiar. In my searches I have been surprised at the fund of information which remains unpublished in the archives of research organizations, in the notebooks of designers and testing engineers and in the experiences of all. It is this information we want to tap. Unfortunately in this country many men are very diffident about publishing particulars of their achievements or of problems solved, partly because they think the scientific and technical world would not be interested, and also because of the undoubted effort involved. The various world-wide extracts of technical journals reveal the dearth of material published by British technicians in comparison with the information which should be available. It was not in such a reticent mood that the great British scientists made known their discoveries to the world. They gave freely and without delay of the best of their knowledge, and so progress was stimulated in all directions. Their motto was "Science for science' sake." This should also be ours. Such an ideal is not impracticable in these days, and I am sure that those who take the trouble to review the work carried out by this Section and its predecessor (the Meter Engineers' Technical Association) will find ample evidence that there are those who have been actuated by some such desire. As members of an Institution with a great tradition whose aim is to encourage the science which will bring electricity to the service of man, let us each add our quota to the store of knowledge which will ease the path to progress.

WESTERN CENTRE: CHAIRMAN'S ADDRESS

By J. Wayne-Morgan, M.C., Member.

"THE ENGINEER IN PUBLIC LIFE."

(*Address delivered at* Cardiff, 12*th October*, 1931.)

Before proceeding to deal with my main theme I should like to pay tribute to the memory of that man who first showed the way towards the great electrical era in which we are privileged to live.

From what is known of the later life of Michael Faraday, it is evident that, though a philosopher in taste and mode of life, he was in after years to acquire knowledge of every kind not merely for its own sake but also because of its effect in improving the mental attitude toward the general problems of life, both on his own behalf and on that of his fellow creatures. We read of his earnest debates with a few friends who met at regular intervals as a kind of mutual improvement society for the discussion of scientific and kindred matters, and throughout his later life he displayed a keen interest in the minor social conditions of his time. Never a rich man, and debarred on account of the nature of his occupation from taking any active part in the affairs of the community, we learn that he bestowed large sums annually upon the sick and needy, retaining for himself only sufficient for the small scale upon which his household was maintained. We are therefore forced to the conclusion that had the word "progress," in its political sense, been in use in Faraday's time, he would have stood, not for the radical disorganization of all existing—and especially of time-honoured—institutions and customs, nor for a reckless embarkation upon any and every scheme that could be called new, but rather for that real progress in which the benefit of the community, assessed with proper scrutiny and perspective, is the ultimate object. It is possible that, had he been able to visualize the industrial changes that would result from his discoveries, he would have delivered a word of warning, lest the many resultant benefits he foresaw should be discounted. If he were among us to-day he would be the first to ask how we are using the science in which he took the first definite step.

The rapid succession of extraordinary events which have shaken the foundations of our country within the last two months has induced me to select for this address the subject of "The Engineer in Public Life." The engineer of to-day has up to the present taken very little active part in the administration of affairs, either national or local. In this respect an important national asset is not being fully utilized, and in addressing engineers I would urge individual consideration of this matter, which, always important, has never been more so than in the present national crisis.

Although the community does not generally recognize that to a large extent it owes its well-being to the engineer, a little consideration will make the fact apparent. While it is certainly true that the results of some engineering activities have brought about many of the present difficult social conditions, this only follows in the ordinary course of events and is partly due to the mismanagement of the gifts bestowed upon the world by the engineer. Similarly the way out of the present difficulties will be found through the engineer's activity alone.

Let us first consider the main directions in which modern life differs from that of a century ago. We have improved the general standard of living by providing a wider variety and availability of foods, increased variety of amenities and improved transport and communication services; the latter have brought closer together the various communities which make up the nations of the world, and are now bringing together the nations themselves. Comparison of the stage-coach and sailing ship with the modern locomotive (steam or electric), ocean liner and air liner, illustrates in a striking manner the bearing of the engineer's work on but a single one of those features which contribute to our well-being. By tracing the history of the developments of the last century one sees that from the work of the engineer grew the amazingly rapid progress and prosperity of that century, which made Great Britain the leading industrial country of the world. From the exploitation of the engineer's developments arose the concentration and congestion of masses of workers in the industrial areas, unfortunately bringing into being one of our modern social evils.

Many engineering developments are already tending to ameliorate these conditions, but it rests with the engineer to remedy them completely and to provide the solution to many other problems which have become of increasing importance with the growth of the population. Prominent among these problems are those relating to building construction, sanitation, ventilation of public buildings, and smoke abatement; let us consider for a moment how engineers might with advantage approach such questions.

Dealing first with building construction, a movement which is already afoot in such areas as Central London aims at the erection of large tenement structures providing on the minimum ground area the maximum accommodation compatible with modern standards of hygiene. These buildings represent an enormous advance upon those available 50 years ago, but a vast field of improvement still remains in which the engineer, working in co-operation with the architect, can exert his efforts to great advantage. Electricity can be employed to a far greater extent than at present, as is shown by the degree of saturation obtained in the centre of New York, and only by the co-ordination of the scientific knowledge of the electrical engineer with the domestic experience of the housewife can an approach to the ideal be made.

It is reassuring to see that the membership of the Electrical Association for Women is increasing rapidly throughout the country, and that at each branch every care is taken to ensure that the members are made aware of the scope of electric power in dealing with all classes of domestic work. There can be little doubt that with such a large number of intelligent supporters progress in the development of the electric home will be rapid. At the same time, due place must be given to the resources of the gas industry in connection with domestic work, as it would be foolish to claim that electrical energy is the panacea for all domestic difficulties. As I have already indicated, it rests with the scientific engineer so to guide the community into the right channels of progress that each resource may be used to the best advantage.

If technical skill is necessary in building design, it is still more necessary in overcoming the difficulties of sanitation and ventilation, and it is my opinion that the application of electricity to these branches of engineering has not been developed to the fullest possible extent. It seems highly probable that in the future some electrolytic means of dealing with sewage will be perfected, and that the ionization of air could be carried out to a greater extent. No great advance will, however, be possible unless the several branches of engineering knowledge combine to discuss the various difficulties; in fact, alone, each branch can make but little progress.

The existence of the smoke abatement problem must to some extent be laid at the door of those responsible for the mechanization of industry and the consequent increased amount of coal burnt in the raw state. The question of political action, necessary to control the individual, holds a position of greater importance in connection with this problem than with the others, and engineers must therefore consider it all the more seriously in the light of the remarks I intend to make later in this address. Before passing on, however, it is interesting to study the position of Cardiff in relation to other large industrial centres. "The Smoke Abatement Handbook" shows that in the matter of total solids deposited per annum Cardiff holds third place with 102 lb. per acre, only two other localities in Great Britain having a lower figure; on the other hand its rainfall is given as 45 inches—a figure which is only exceeded by two Lancashire districts. The annual cost of smoke in Cardiff is given as £300 000, but on the basis of cost per unit of population Cardiff is placed in a fairly satisfactory position in comparison with other towns.

In addition to the above-mentioned directions in which the engineer's activities might be applied, there remain a host of others such as the universal availability of water and of electrical and other power supplies, and a vastly improved transport system which will render no longer necessary the grouping of industrial establishments in congested areas. The distribution of industries generally over larger areas will no doubt eventually lead to great changes in local government. As there will probably be far fewer governing bodies and they will be responsible for the administration of much larger areas, it will be more necessary than ever that engineers should be represented on those bodies.

So far I have referred to engineering in general; I now propose to deal more particularly with electrical matters. The electrical engineer, whether he likes or not, is bound in the future to take much more interest in politics than he has done in the past. The passing of the Electricity Act of 1926 has, in my opinion, entirely changed the position of the electrical engineer with regard to politics. The Central Electricity Board with its national "grid" scheme is an accomplished fact, and work has been started on the portion of the scheme dealing with our own particular area. While some of us, no doubt, have opinions of our own as to the desirability of taking a bulk supply in preference to running our own generating plant, in the interests of the national weal we should sink our more parochial feelings and unite to ensure that, as far as we can make it so, the whole scheme shall be a genuine success. We have yet to gain operating experience of the "grid" lines, to learn their behaviour under conditions of varying loads, surge, sea-mist, lightning, storms, and all the other afflictions that overhead lines are heir to. We need, however, have no misgivings as to the final successful result, for, provided we engineers work whole-heartedly together, we can overcome all the difficulties which may arise. From the commercial point of view it is essential, the more so in view of recent events, to make the fullest possible use of the service offered by the Central Electricity Board. If this is not done the scheme will be a gigantic failure and a further burden on our already overloaded shoulders. The most dangerous aspect of the scheme is the possibility of its becoming a plank for party politics, and we engineers must use every effort to prevent this happening. If political instead of engineering considerations are allowed to become deciding factors in the future policy of the "grid" scheme, nothing but failure can be expected.

The electrification of the main railways is a matter open to much discussion, and although the carrying-out of such a vast scheme would no doubt provide a steady and welcome supply of work, spread over a period of many years, I sincerely hope that the final decision whether or not to proceed with this conversion will be based on engineering facts, and not on considerations of political policy.

Some of you will no doubt consider that my views with regard to the political bogy are without justification, but we have already seen how political interference, due to wild and rash electioneering promises, has reduced certain industries to a state of chaos from which it will take them years to recover, if ever they do so. In view of the important effect of the engineer's work on the well-being of the community it is his duty to devote more of his time and effort to the efficient organization and administration of public affairs, for hitherto he has played an insignificant and disproportionate part in this work.

In trying to discover the reasons why the engineer has played so small a part in politics one is forced to the conclusion that it is primarily because he is a "doer" and not a "talker." Perhaps the greatest improvement that could be made in the government of Great Britain would be to establish control by fewer "talkers" and more "doers." It is interesting to examine the lists of Cabinet and other Ministers in the late Government and its immediate predecessors, and to consider the fields of activity in which these men may be considered expert. The percentage figures are given in the next column.

The representation of the various classes of occupations —engineering included—seems to be disproportionate. The industrial difficulties of the country may be due, at least in part, to the fact that the reins of government have been so largely in the hands of lawyers and those whom we label, for want of a better term, "professional politicians." I do not suggest that the ideal Government should consist of members representing occupations in proportion to the numbers of the population engaged in them; that would be democracy *ad absurdum.*

Railways	under	1
Accountancy	,,	1
Engineering	,,	1
Business		2
Professors, lecturers, teachers		4
Diplomatic service, civil service, post office, police, etc.		4
Trade union officials		4
Editors, journalists, etc.		7
Mining		6
Army and Navy		17
Law		20
Politicians		33
		100

In view of such considerations as those I have mentioned I feel that it is essential for engineers to take a greater part in the government of the country, but I hope that those who do so will remain engineers and not become "professional engineering politicians."

MERSEY AND NORTH WALES (LIVERPOOL) CENTRE: CHAIRMAN'S ADDRESS

By P. M. Hogg, B.Sc., Member.

"THE APPLICATION OF ELECTRICITY TO THE MEASUREMENT OF TEMPERATURE."

(*Address delivered at* LIVERPOOL, *19th October*, 1931.)

The choice of the subject of this address was not an easy matter, but after consideration I decided to limit its scope to one of the applications of electricity with which my daily work brings me into contact. I chose the measurement of temperature because it is an important application which, perhaps, has not received in the past the attention it deserves from the electrical engineer.

In any attempt to measure temperature the first difficulty which arises is that temperature is not—strictly speaking—a measurable quantity. In true measurement only the magnitude of the unit has to be arbitrarily chosen, and the measurement of any quantity consists in counting how many times the chosen unit must be taken, in order, by addition, to obtain the equivalent of the quantity in question. In this sense, units of temperature cannot be added, and temperature therefore cannot be truly measured. If, however, a *scale* of temperature be chosen, any temperature can be referred to this scale, and the "measurement" of temperature consists in the making of this reference.

In 1848 Lord Kelvin—then William Thomson—proposed an "ideal" temperature scale which was based on the second law of thermodynamics and which was defined to be such that "the absolute values of two temperatures are to one another in the proportion of the heat taken in to the heat rejected in a reversible thermodynamic engine working with a source and refrigerator at the higher and lower of the two temperatures respectively." Numerical values have been assigned to this scale by numbering the temperatures of melting ice and of the vapour of pure water boiling under standard atmospheric pressure 0° and 100° respectively. This "ideal" scale, so numbered, is known as the "thermodynamic Centigrade scale," and is the ultimate standard of reference to-day, although its rigorous realization is impossible.

The practical scale of temperature has been gradually evolved, and in 1927 a scale, known as the International Temperature Scale, was approved, for international use, by the General Conference of Weights and Measures. This scale, while it conforms very closely to the thermodynamic Centigrade scale, is purely empirical because it is based upon a number of fixed and reproducible temperatures to which numerical values are assigned, and upon the indication of standard interpolation instruments calibrated at these temperatures according to a specified procedure.

The specification of the International Temperature Scale is as follows:—

Basic Fixed Points.

(*a*) Temperature of equilibrium between liquid and gaseous oxygen at the pressure of one standard atmosphere (oxygen point) = − 182·97° C.

$$t_p = t_{760} + 0{\cdot}0126(p - 760) - 0{\cdot}0000065(p - 760)^2$$

(*b*) Temperature of equilibrium between ice and air-saturated water at normal atmospheric pressure (ice point) = 0·000° C.

(*c*) Temperature of equilibrium between liquid water and its vapour at the pressure of one standard atmosphere (steam point) = 100·000° C.

$$t_p = t_{760} + 0{\cdot}0367(p - 760) - 0{\cdot}000023(p - 760)^2$$

(*d*) Temperature of equilibrium between liquid sulphur and its vapour at the pressure of one standard atmosphere (sulphur point) = 444·60° C.

$$t_p = t_{760} + 0{\cdot}0909(p - 760) - 0{\cdot}000048(p - 760)^2$$

(*e*) Temperature of equilibrium between solid silver and liquid silver at normal atmospheric pressure (silver point) = 960·5° C.

(*f*) Temperature of equilibrium between solid gold and liquid gold at normal atmospheric pressure (gold point) = 1 063° C.

Standard atmospheric pressure is defined as the pressure due to a column of mercury 760 mm high, having a mass of 13·5951 gramme per cm^3, subject to a gravitational acceleration of 980·665 cm per sec. per sec., and is equal to 1 013 250 dynes/cm^2.

The pressure-correction formulæ represent the temperature (t_p) as a function of vapour pressure (p) over a range of 680 to 780 mm of mercury.

Interpolation.

(*a*) From 0° C. (ice point) to 660° C. the temperature t is deduced from the resistance R_t of a standard platinum resistance thermometer by means of the formula

$$R_t = R_0(1 + At + Bt^2)$$

The constants R_0, A and B of this formula are to be determined by calibration at the ice, steam and sulphur points respectively.

The purity and physical condition of the platinum of which the thermometer is made should be such that the ratio R_t/R_0 shall not be less than 1·390 for $t = 100°$, and 2·645 for $t = 444{\cdot}6°$.

(*b*) From − 190° C. to 0° C. (ice point) the temperature

t is deduced from the resistance R_t of a standard platinum resistance thermometer by means of the formula

$$R_t = R_0\left[1 + At + Bt^2 + C(t - 100)t^3\right]$$

The constants R_0, A and B are to be determined as specified above, and the additional constant C is determined by calibration at the oxygen point.

The standard thermometer for use below 0° C. must in addition have a ratio R_t/R_0 less than $0 \cdot 250$ for $t = -182 \cdot 97°$.

(c) From 660° C. to 1 063° C. (gold point) the temperature t is deduced from the electromotive force e of a standard platinum/platinum-rhodium thermo-couple, one junction of which is kept at a constant temperature of 0° C. while the other is at the temperature t defined by the formula

$$e = a + bt + ct^2$$

The constants a, b and c are to be determined by calibration at the freezing point of antimony, and at the silver and gold points.

It should be noted that as the freezing point of antimony is not one of the " basic fixed points " and as its temperature comes within the range of the platinum resistance thermometer, the value taken for this freezing point is that determined by resistance thermometer for the particular sample of antimony used. This procedure ensures the continuity of the scale at 660° C.

The platinum of the standard thermo-couple is to be of such purity that the ratio R_t/R_0 is initially not less than $1 \cdot 390$ for $t = 100°$ C., and the alloy is to consist of 90 per cent platinum and 10 per cent rhodium. The completed thermo-couple must develop an electromotive force, when one junction is at 0° C. and the other at the freezing point of gold, of not less than 10 200 nor more than 10 400 international microvolts.

(d) Above 1 063° C. (gold point) the temperature t is determined by means of the ratio of the intensity J_2 of monochromatic visible radiation of wavelength λ cm emitted by a black body at the temperature t_2 to the intensity J_1 of radiation of the same wavelength emitted by a black body at the gold point, by means of the formula

$$\log_e \frac{J_2}{J_1} = \frac{C_2}{\lambda}\left[\frac{1}{1\,336} - \frac{1}{(t + 273)}\right]$$

The constant C_2 is taken as $1 \cdot 432$ cm-degrees. The equation is valid if $\lambda(t + 273)$ is less than $0 \cdot 3$ cm-degree.

ELECTRICAL PYROMETERS.

It will be seen that over the range between − 190° C. and 1 063° C. on the international scale the definition of temperature involves the use of two electrical pyrometers, the platinum resistance thermometer and the platinum/platinum-rhodium thermo-couple.

The Platinum Resistance Thermometer.

The measurement of temperature based on the relation between the temperature and the resistance of a platinum wire was first proposed by Dr. C. W. (later Sir William) Siemens in 1871. This method was rapidly adopted but was quickly abandoned and not revived until nearly twenty years later. That it fell into disuse was largely due to the fact that the platinum wire in the early resistance thermometers made by Siemens was enclosed in an iron tube, and was thus contaminated at high temperatures by reduced silicon from the pipeclay cylinder on which it was wound. This was peculiarly unfortunate because the measurement of temperature by means of the platinum resistance thermometer is now recognized to be probably unequalled in accuracy and reliability. If of the highest purity obtainable, platinum has the two essential properties required by the method, namely that its resistance increases continuously with increase of temperature and that its resistance at any given temperature remains constant. The coefficient of increase of resistance with temperature is a good indication of the purity of platinum, as any impurity lowers this coefficient very considerably.

The resistance of a standard platinum resistance thermometer at 0° C. is often chosen to be such that the increase of resistance is 10 ohms when its temperature is raised from 0° C. to 100° C. This resistance at 0° C. is about $25 \cdot 6$ ohms.

The Platinum/Platinum-Rhodium Thermo-couple.

In 1821 Seebeck discovered that if two wires of dissimilar metals are joined together at their ends and a difference of temperature is maintained between the two junctions an electric current flows round the closed circuit. This current is due to the algebraic sum of four electromotive forces acting round the circuit:—

(a) An electromotive force at the point of contact of the metals at each of the two junctions. The magnitude of each electromotive force depends on the temperature at the point of contact and on the metals chosen.

(b) An electromotive force between the ends of each of the two wires. The magnitude of each electromotive force depends on the difference of temperature between the ends of the wire and on the metal of which the wire is made.

Thus with any two given metals the total electromotive force acting round the circuit depends on the difference of temperature between the hot and cold junctions. If the circuit is broken at any point and the ends formed by the break are joined by a wire of a third metal, the total electromotive force acting round the circuit remains unchanged if the ends of this third wire are at the same temperature. This enables the total electromotive force to be measured, as the wire of the third metal can be the circuit of a measuring instrument. If, then, the temperature of the cold junction is known, the temperature of the hot junction can be determined by the measurement of the total electromotive force in the circuit, provided the relation between that electromotive force and the difference of temperature between the hot and cold junction has been established for the two metals.

It is interesting to note that a thermo-electric circuit, such as described, is acting as a heat engine. Normally heat is taken in at the hot junction, is given out at the cold junction and is taken in or given out along the wires. The difference between the total reversible heat taken in and the total reversible heat given out is the source of the electrical energy, and when unit quantity of electricity passes round the circuit this difference is a measure of the total electromotive force acting round the circuit. This electrical energy, of course, ultimately appears as heat, due to the resistance of the circuit.

TEMPERATURE AND "IDEAL BLACK BODY" RADIATION.

Above 1 063° C. on the international scale the definition of temperature is based on the relation between the temperature of a "black body" and the intensity of its emission of a monochromatic visible radiation.

The formula adopted was first deduced by Wien in 1896, and, although it is based on arbitrary assumptions, it closely represents experimental results within the specified limits of temperature and wavelength. Wien's formula applies only to radiation emitted by a black body which is an ideal and not a real body. If radiant energy falls on any real body the radiation is only partly absorbed, the remainder being partly reflected and partly transmitted.

The "perfect" or "ideal" black body is defined to be one which would absorb all the radiation falling on it. This body when cold would be absolutely black due to the entire absence of any reflected light. The ideal black body which is the perfect absorber is also the perfect radiator, i.e. at any given temperature no body can radiate energy at a greater rate per unit area of surface than does this black body at the same temperature. While no known substance has a surface radiation which is so complete as that of the black body, the radiation inside any enclosure whose walls are at a uniform temperature is identical with the radiation of the black body at the same temperature. This very important conception of the ideal black body, and its practical realization, are due to Kirchhoff.

INDUSTRIAL PYROMETRY.

Industrial pyrometry may be divided into three classes: (1) Resistance pyrometry; (2) thermo-electric pyrometry; and (3) radiation pyrometry.

(1) *Resistance Pyrometry.*

In the industrial type of resistance pyrometer which can be used to measure temperatures up to 550° C. the resistance element generally consists of a fine platinum wire having a resistance of about 100 ohms at 0° C. This wire is wound on a porcelain cylinder which is glazed overall and enclosed in a suitable protecting tube. When the temperatures to be measured do not exceed 250° C. a nickel wire is sometimes used as the resistance element.

Fig. 1 shows the connections of a typical permanent multi-point resistance pyrometer installation. The temperature of a selected resistance element is measured by means of an unbalanced Wheatstone bridge in which three arms are constant resistances, while the fourth arm consists of a constant resistance in series with the resistance element and its leads. Two ranges of temperatures are scaled on the galvanometer, the desired range being selected by means of the change-over switch S. The values of the constant resistances are such that no current flows in the galvanometer G when the resistance element is exposed to the lowest temperature of the range in use. The deflection of the galvanometer at the higher temperatures depends not only on the increased resistance of the element but also on the value of the battery current and the sensitivity of the galvanometer.

To ensure that these conditions, when temperatures are being measured, are equivalent to those under which the galvanometer was originally calibrated, a constant test resistance is substituted for a resistance element by means of the selector switch. The sensitivity of the galvanometer is then adjusted by means of a magnetic shunt until the pointer is deflected to a special test mark on the scale. This calibration is made on the assumption that the resistance of the leads remains constant at a specified value (about 2 ohms), and the resistance of the leads between each pyrometer and the bridge is adjusted to this value by means of an equalizing resistance. The resistance of the leads may, however, vary considerably with the temperature to be measured, but in industrial practice this variation may be neglected if the resistance of the element at 0° C. is over 30 times the resistance of the leads.

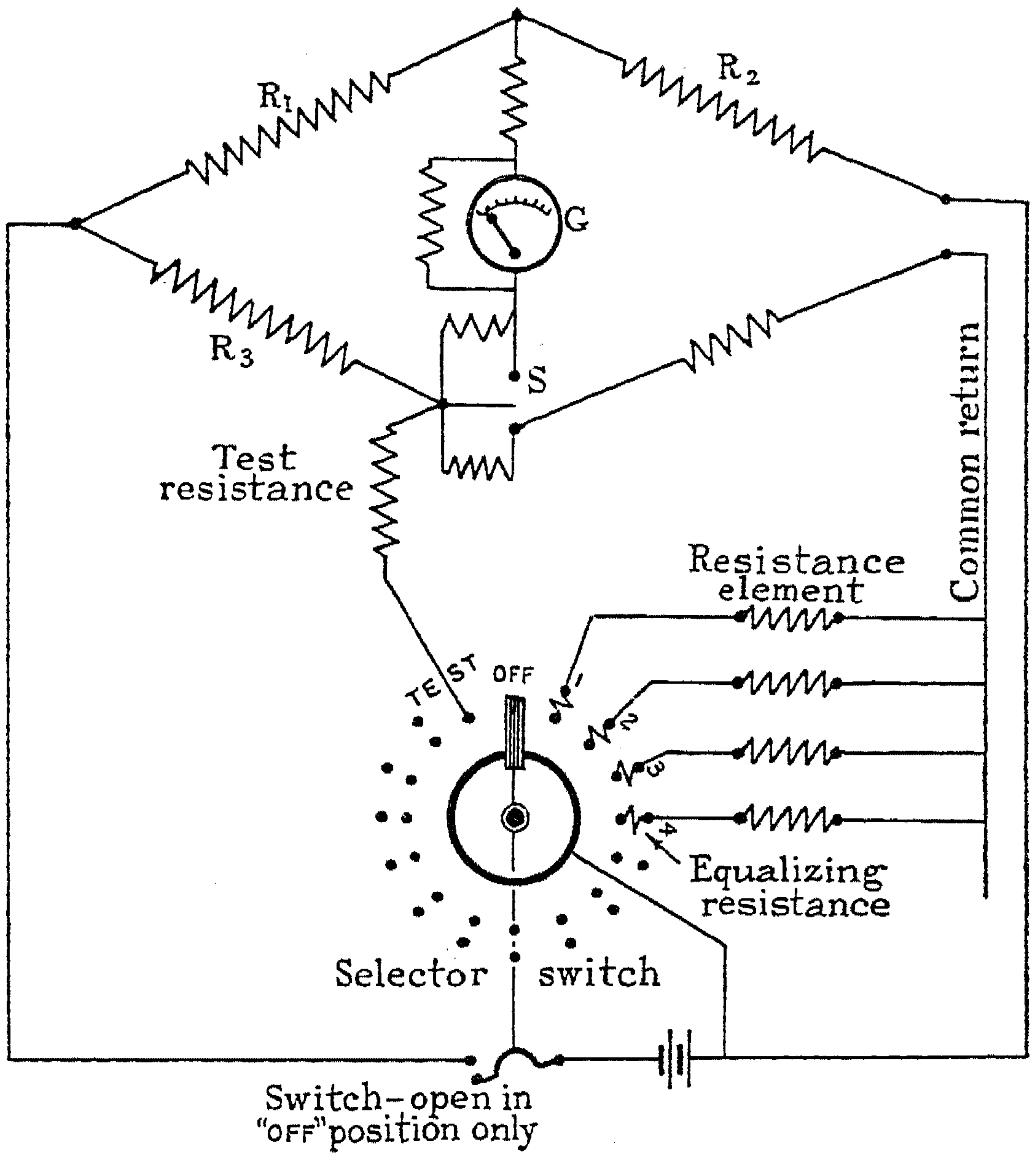

FIG. 1.—Multi-point resistance pyrometer installation.

In another form of resistance pyrometer which is used in more accurate testing work to measure temperatures up to 1 100° C., the resistance element consists of a much heavier platinum wire wound on a mica frame and enclosed in a porcelain tube. The resistance of this element, which may be only about 2·6 ohms at 0° C., is measured by means of a balanced Wheatstone bridge the circuit of which is shown in Fig. 2. In this case, as the variation of the resistance of the leads cannot be neglected, four leads of equal cross-section are run between the pyrometer and the bridge, the two extra leads, known as the "compensating leads," being connected together at the resistance element. The two ratio arms of the bridge are equal and constant resistances. The third arm is formed by two leads and the unknown resistance of the element, while the fourth arm consists of the two compensating leads and the variable balancing resistance. Thus, when no current flows in the galvanometer circuit, the balancing resistance is equal to the unknown resistance of the element, provided the resistance of one pair of leads equals that of the other pair. As the four leads are of equal length and cross-section and have the same temperature gradient this condition is always satisfied.

The balancing resistance is sometimes wound on a drum which is rotated to obtain a balance, and the drum is then scaled to indicate temperature directly.

The resistance pyrometer is very suitable where an open scale at some given temperature is required, and for the accurate measurement of comparatively low temperatures.

In industry generally, however, the relative importance of resistance pyrometry has probably decreased, and temperatures above 300° C. are now more often measured by means of pyrometers of the thermo-electric type.

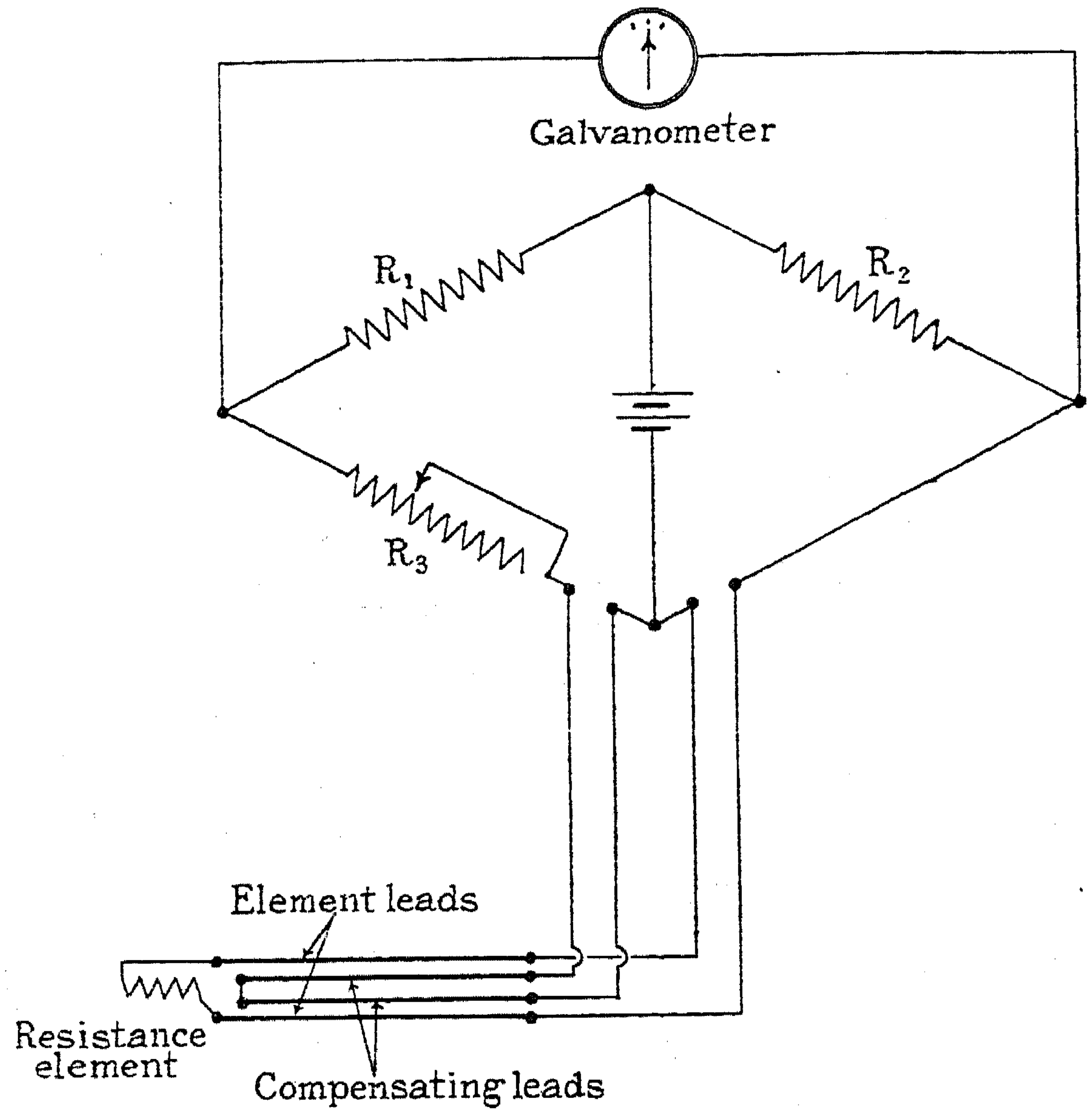

FIG. 2.—Resistance pyrometer with 4-lead compensation.

(2) *Thermo-Electric Pyrometry.*

A multi-point thermo-electric pyrometer installation comprises: (*a*) The thermo-couples; (*b*) the leads between the thermo-couples and the cold junction; (*c*) the cold junction; (*d*) the indicator or recorder; and (*e*) the selector switch.

(*a*) *Thermo-couples*—A thermo-couple consists of two wires of dissimilar metals or alloys which are welded together at one end to form the hot junction. These wires or elements are insulated throughout their length and enclosed in a protecting tube, and their free ends are connected to terminals to enable the thermo-electric circuit to be completed. The metals or alloys employed as the thermo-electric elements are those which resist change and corrosion and together develop an easily measured electromotive force which increases continuously with increase of temperature throughout the required temperature range. The choice of the two metals actually used in any particular case depends largely on the maximum temperature to be measured and on the desired accuracy of measurement.

A thermo-couple having one element of pure platinum and the other of an alloy of 90 per cent platinum and 10 per cent rhodium can be used to measure temperatures up to 1 500° C., but adequate protection of the elements from contamination becomes very difficult at temperatures above 1 300° C. For continuous use above 1 100° C. it is the only satisfactory thermo-couple and in the measurement of lower temperatures its superior constancy of calibration often renders its use desirable and economical.

Base metals and their alloys are, however, very widely used as elements for the measurement of temperatures up to 1 100° C.

In practice the base-metal thermo-couples most commonly employed are:—

Copper/constantan (60 per cent copper; 40 per cent nickel) for use up to 350° C.
Iron/constantan for use up to 850° C.
Nickel-chromium/Nickel-aluminium for use up to 1 100° C.

This last combination, due to Hoskins, can be used up to 1 300° C. for short periods.

The nickel-chromium element is an alloy of 90 per cent nickel and 10 per cent chromium, and the nickel-aluminium element an alloy of 98 per cent nickel and about 2 per cent of aluminium with small quantities of silicon and manganese.

The electromotive force developed by these base-metal thermo-couples is between 4 and 7 times that developed by the rare-metal thermo-couple at the same temperature.

Protecting tubes.—The selection of the protecting tube is very important, as the life and behaviour of the thermo-couple depends on the degree to which it is protected from contamination by high-temperature gases and fumes.

The desired properties of a protecting tube are the ability to withstand high temperatures and sudden changes of temperature, a low porosity to gases, and high mechanical strength.

One or more of the following tubes are usually employed:—

Steel tube up to about 800° C.	Base-metal thermo-couples.
Calorized steel tube up to about 900° C.	
Nichrome tube up to about 1 100° C.	
Fused silica tube up to about 1 100° C.	Rare-metal thermo-couples.
Porcelain tube up to about 1 400° C.	

Porcelain can withstand a higher temperature than fused silica and is more impervious to gases, but silica can stand sudden changes of temperature which would destroy porcelain.

(*b*) *Leads between the thermo-couples and cold junction.*—As the temperature of the hot junction can be determined only if the temperature of the cold junction is known, the latter must be situated where its temperature can be measured. A very convenient position is at the indicator. If the thermo-couple were connected to the indicator by means of copper cables, the cold junction would be situated very inconveniently at the thermo-couple terminals and it is therefore very often transferred from that position to the indicator by the use of " compensating " leads of dissimilar metals which together have the same thermo-electric characteristics as the two metals of the thermo-couples.

When base-metal thermo-couples are used these leads are of the same metals as those of the thermo-couple elements, and simply extend these elements to the cold junction.

When rare-metal thermo-couples are employed, one lead is of copper and the other of an alloy of nickel and copper, the copper wire being connected to the platinum-rhodium element of the thermo-couple. These leads do not compensate individually, but together they develop very nearly the same electromotive force as the platinum/platinum-rhodium combination at any hot junction temperature up to 200° C. Great care must be taken to ensure that the compensating leads are correctly connected to the thermo-couple.

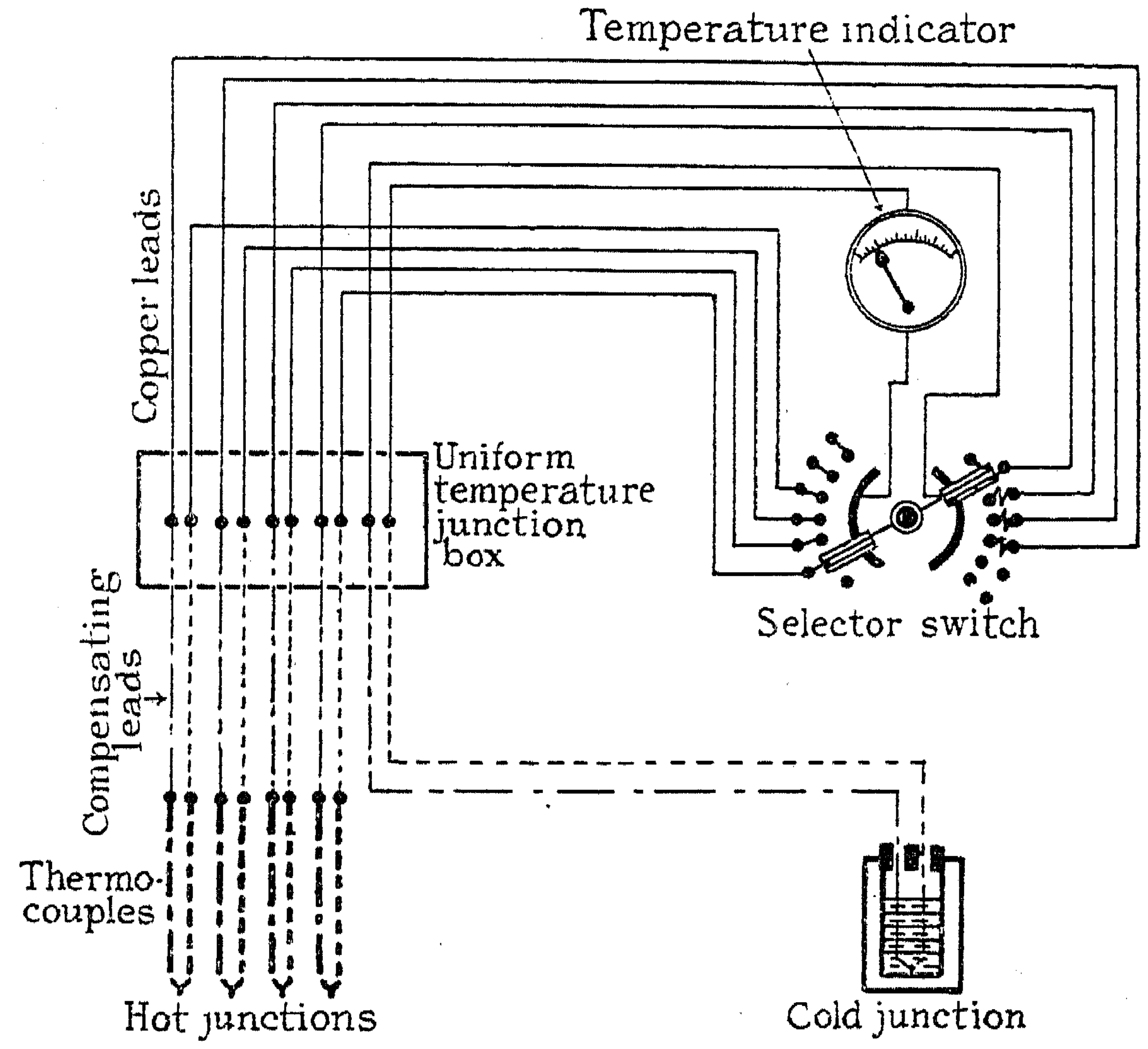

FIG. 3.—Multi-point thermo-electric pyrometer installation.

If in a thermo-couple installation there are several thermo-couples which are fairly close together but at some considerable distance from the indicator, the relatively expensive compensating leads may be run from the thermo-couples to a " uniform temperature " junction box situated near them, and only one pair of compensating leads from this junction box to the cold junction. The remainder of the wiring can then be run in ordinary copper cable and the common cold junction used for each thermo-couple by means of a selector switch. It should be particularly noted that in this arrangement the temperature inside the junction box need not be known or constant as no error is introduced, provided this temperature is uniform. A common return lead is often used in a multipoint thermo-couple installation, but an individual return lead from each thermo-couple enables earthing and leakage troubles to be quickly detected and is to be preferred. High insulation resistance of a thermo-couple installation is an essential to success.

(*c*) *The cold junction.*—In accurate scientific work the temperature of the thermo-couple cold junction is kept at 0° C. by means of melting ice. In industrial work, however, it is usually placed in a vacuum flask which is filled with oil and fitted with a thermometer. This does not, of course, maintain a constant cold-junction temperature, but it prevents rapid temperature variation and meets all normal industrial requirements.

If a deflecting type of indicator is used the necessary cold-junction temperature correction can be simply made by setting the pointer to indicate the cold-junction temperature instead of zero when the indicator is on open circuit. In some indicators this is done automatically by means of a bimetallic spring, and in this case the cold junction must, of course, be situated at the indicator.

(*d*) *The indicator or recorder.*—A millivoltmeter having a resistance of over 10 ohms per millivolt required to give full-scale deflection and scaled to indicate temperature directly is usually employed to measure the electromotive force developed by the thermo-couple. This instrument actually measures the current flowing in the thermo-electric circuit, and this current is proportional to the developed electromotive force only if the resistance of that circuit remains constant.

Over the range of temperature to be measured the temperature and resistance of the thermo-couple and its leads may vary considerably, but the percentage variation of the total resistance of the thermo-electric circuit can be neglected if the constant resistance of the indicator is high compared with this variable resistance.

The millivoltmeter is calibrated to indicate correctly when connected to an external circuit having a resistance which is not less than that of a thermo-couple and the longest leads. After the leads have been run the combined resistance of each thermo-couple and its lead is measured and the necessary equalizing resistance added.

If a continuous record of temperature is required a recorder may be used instead of an indicator. Generally this recorder is similar to the usual recording voltmeter, but as the torque of the sensitive millivoltmeter is too small to overcome the friction of the pen on the paper of the chart a " chopper bar " arrangement is fitted. This bar, which extends over the whole scale, is alternately raised to allow the pointer to swing freely and to take up its position without touching the paper, and dropped to depress the pointer and so mark that position on the chart.

In multi-point recorders the clockwork which operates the " chopper bar " also operates a selector switch which connects each thermo-couple to the millivoltmeter in turn. In this way the temperature of as many as six thermo-couple positions can be recorded on one chart.

(*e*) *The selector switch.*—The selector switch is usually totally enclosed to protect the contacts from corrosive gases and fumes. The contacts should be large, although the maximum current is of the order of 100 microamperes.

Fig. 3 is a diagram of a typical multi-point thermo-electric pyrometer installation.

(3) *Radiation Pyrometry.*

All radiation pyrometers are based on some relation between the temperature of the black body and its emission of radiant energy, and are calibrated accordingly.

In the open, different substances at any given temperature emit very different intensities of radiation, and these unequal intensities are all lower than the intensity of the radiation emitted by the black body at the same temperature. Thus, any radiation pyrometer sighted on a hot body in the open indicates an apparent temperature which is lower than the true temperature. When, as is often the case, temperature control is all that is needed, this is of no real importance, as, provided the readings are always taken under the same conditions, variation of temperature can be detected.

When, however, the measurement of temperature is required, the conditions under which a radiation pyrometer is used must be such that the radiation from the hot body is that of the black body at the same temperature. In practice these conditions can be realized because if a body of any substance is in an enclosure, and if that body and the walls of the enclosure are at the same temperature, the intensity of the radiation leaving the body is equal to that emitted by the black body at this uniform temperature.

The intensity of radiation actually emitted by the enclosed body is the same as that emitted by it at the same temperature in the open, but the leaving intensity is raised to this equality by the body reflecting a part of the radiation falling on it from the surrounding enclosure. In industry many furnaces approximate fairly closely to this ideal uniform temperature enclosure, and it is this fact which enables industrial temperatures to be measured by means of radiation pyrometry.

The degree of this approximation can be judged by the appearance of the interior of a furnace, because detail is largely lost if the black-body conditions are good. If these conditions were perfect, the intensity of radiation would be perfectly uniform and no detail could be seen.

Radiation pyrometers cannot be used satisfactorily when flame or smoke is present, but this difficulty can often be overcome and black-body conditions improved generally by inserting through the wall of the furnace a tube with a closed inner end on to which the pyrometer can be sighted.

Radiation pyrometry may be divided into two classes: —(1) Total radiation pyrometry; and (2) optical pyrometry.

(1) *Total-Radiation Pyrometry.*

Total-radiation pyrometry is based on the relation between the temperature of a black body and the total energy radiated per unit area of its surface in unit time.

This relation can be expressed by the equation

$$W = \sigma(T_1^4 - T_0^4)$$

where W = energy radiated per unit area in unit time;
σ = experimental constant, the numerical value of which depends on the units employed;
T_1 = absolute temperature of the black body source;
T_0 = absolute temperature of the surroundings which receive the radiation.

In the Féry total-radiation pyrometer shown in Fig. 4 the radiation at all wavelengths from the hot source is focused by means of a concave mirror of stainless metal upon the hot junction of a thermo-couple which is shielded from direct radiation, and so long as the image of the source completely covers this limiting opening of about 1·5 mm in diameter, the indication of the pyrometer is very approximately independent of the distance between the source and the pyrometer.

Errors are introduced by radiation from this limiting diaphragm and from the case of the pyrometer falling on the thermo-couple, and by the absorption of the infra-red rays by some products of combustion such as carbon dioxide, and large errors are also introduced by departure from black-body conditions.

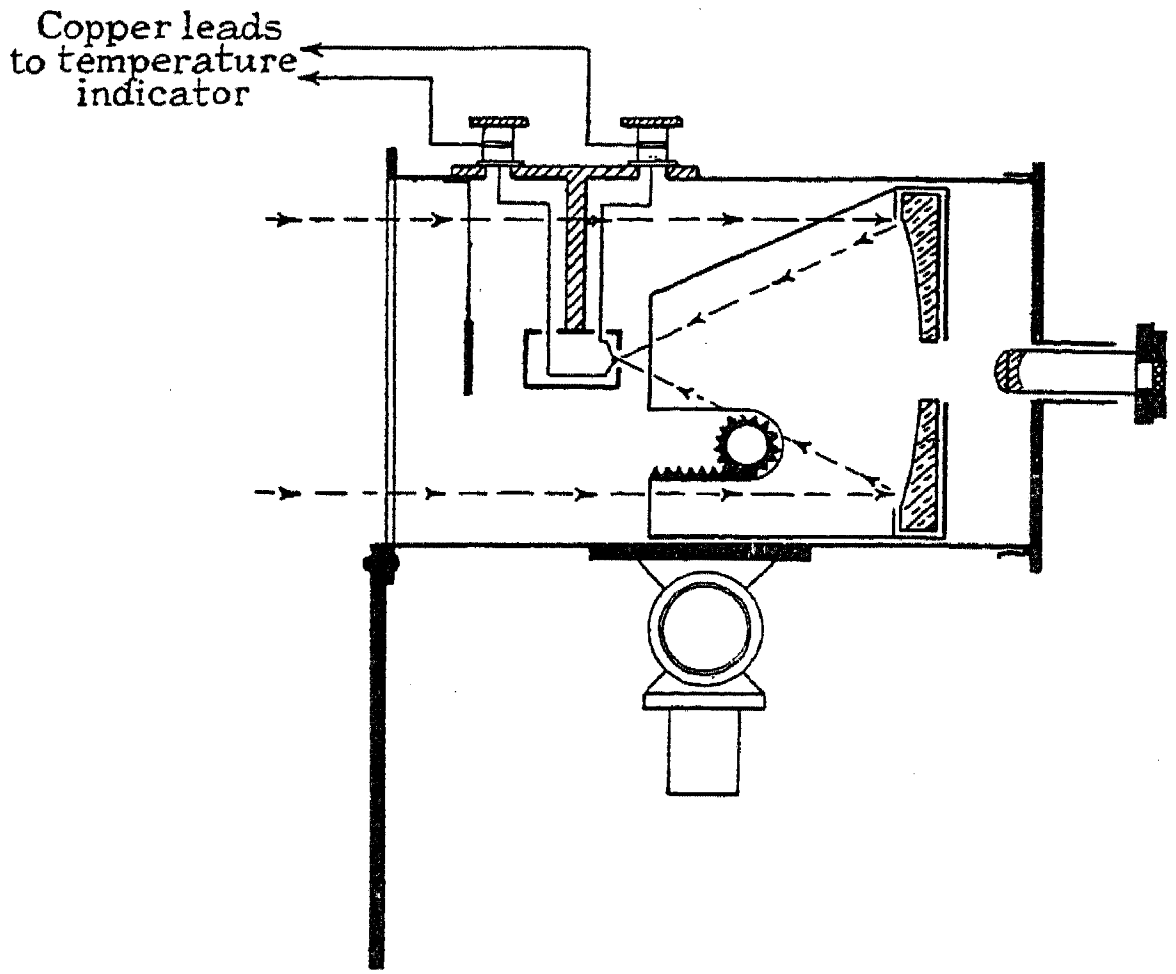

FIG. 4.—Total-radiation pyrometer (Féry).

The chief advantage of the total-radiation pyrometer is that it can be used with a recorder.

(2) *Optical Pyrometry.*

Optical pyrometry is based on the relation between the temperature of the black body and the intensity of a visible radiation of a selected wavelength. The equation expressing this relation has already been given in the specification of the International temperature scale. An examination of this equation will show that the intensity of any visible monochromatic radiation increases very rapidly with increase of the temperature of the black-body source. If, for example, a red light (wavelength $0 \cdot 65\ \mu$) be selected, and if the intensity of this light emitted at 1 100° C. be taken as unity, at 1 400° C. this intensity is over 17, and at 1 700° C. it is over 130.

While any wavelength in the visible spectrum may be chosen for the purpose of measuring the temperature of the source, a red light is usually selected because a red glass transmits only a narrow spectral band of light, and approximately monochromatic radiation is thus easily filtered out. The use of a red light also enables temperatures as low as 700° C. to be measured, as the red rays are the first visible radiation to be emitted by a body with rising temperature.

The disappearing-filament type of optical pyrometer, shown in Fig. 5, consists of a telescope with an objective lens which produces an image of the hot source in the plane of the filament of a small electric lamp placed inside the telescope tube. An eyepiece fitted with a red glass filter enables the brightness of the red ray from this image to be compared with that from the filament through which a current is being passed. The filament current is adjusted by means of a variable resistance until the tip of the filament seems to disappear in the background of the image. This current is then a measure of the temperature of the source. The comparison can be made very accurately and, as the eye is judging the relative intensities of light of one colour, the pyrometer can be used by a colour-blind observer. The indication of the pyrometer is independent of the distance between the source and the pyrometer.

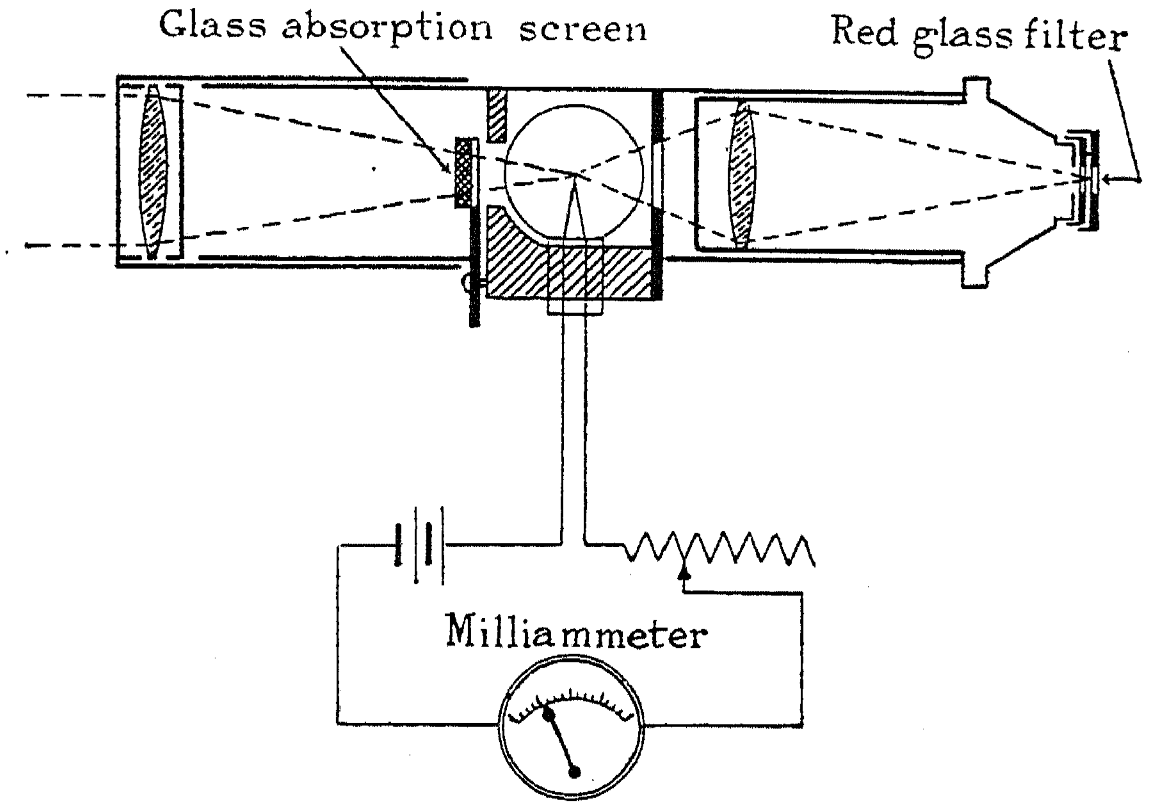

FIG. 5.—Optical pyrometer with disappearing filament.

The lower limit of temperature which can be measured is about 700° C., and the following table gives a typical calibration of the type of lamp used. Each lamp is, of course, separately calibrated.

TABLE.

Disappearing-filament Optical Pyrometer (using light of wavelength 0·65 μ).

Temperature of source	Filament current
° C.	amps.
700	0·232
800	0·256
900	0·282
1 000	0·308
1 100	0·336
1 200	0·364
1 300	0·396
1 400	0·430
1 500	0·464

The lamp filament cannot be safely run at a higher temperature than that required to measure a temperature of 1 500° C., but the range of the pyrometer can be extended indefinitely by inserting one or more absorbing glasses between the objective lens and the filament in order to reduce the intensity of the image by a definite amount. The calibration of the lamp with these absorbing glasses in position can be calculated from its normal calibration without them.

The disappearing-filament optical pyrometer has many advantages over the total-radiation pyrometer. It is more accurate and departure from black-body conditions does not introduce so large an error. Its disadvantage is that it cannot be used with an automatic recorder.

The success of many industrial processes depends on temperature control, and the application of electricity to the measurement of temperature gives the electrical engineer an excellent opportunity of increasing his usefulness in the industrial world.

SCOTTISH CENTRE: CHAIRMAN'S ADDRESS

By Prof. G. W. O. HOWE, D.Sc., Member.

"THE NOMENCLATURE OF THE FUNDAMENTAL CONCEPTS OF ELECTRICAL ENGINEERING."

(*Address delivered at* GLASGOW, *20th October*, 1931.)

"The importance of nomenclature was recognized in the earliest times. One of the first duties that devolved upon Adam on his installation as gardener and keeper of the zoological collection was the naming of the beasts."—OLIVER HEAVISIDE.*

In reading over the paper in the *Philosophical Transactions of the Royal Society* for November 1831 in which Faraday describes in minute detail the experimental discovery and the investigation of electromagnetic induction, I was struck by the entire absence, and indeed the impossibility at that date, of any exact measurement and by the absence of such words as "resistance" and "electromotive force;" and it occurred to me that the history of the development of the conceptions and terms which are now used in electrical engineering would form a very suitable subject for this address.

A large body of interconnected concepts has grown up, and names have been given to these concepts. Their accurate measurement and statement necessitated the adoption of a system of interconnected units, and unfortunately led to the introduction of several systems of units. Names have been given to many of these units. The development of the subject has led to the continual emergence of new concepts, leading to the introduction of new names to describe them and of new units by which to express them. The existence of several systems of units has led to the development of other systems alleged to have all, or most of, the merits of all the older systems and few of their defects, and the supporters of each new system advocate its adoption in place of the several older systems. It is not surprising that there are at the present time considerable differences of opinion as to the meanings to be assigned to certain well-established terms and the names to be assigned to certain phenomena and conceptions, on the relative merits of different units and systems of units, and on the question of allocating names to these units.

Many of the terms commonly employed in electrical engineering were introduced by Faraday; in some cases he used them in the same sense as that in which they are employed to-day, but in other cases the terms are now used in an entirely different sense. It comes as a surprise, for example, to find the word "electromotor" in a letter from Faraday dated November 1834; he uses it, however, to designate a primary cell, a device for imparting motion to electricity; for, he says: "I have no doubt that if a long wire were arranged so as to discharge a single pair of plates, and the spark occurring at the breaking of contact were noted, and then another wire carrying a current in the same direction from another electromotor were placed parallel and close to but without touching the first, the spark obtained on breaking the contact at the first wire would be greater than before." As in the same letter he speaks of a single pair of plates exposing 3 sq. ft. of surface on both sides of the zinc plate, there can be no doubt as to the nature of his "electromotor."

Another strange word which Faraday used to designate a special form of primary cell invented by Dr. Hare of Philadelphia was "calorimotor." He says: "It is in fact a single pair of large plates, each having its power heightened by the induction of others, consequently all the positions and motions of the needles, poles, etc., are opposite to those produced by an apparatus of several plates; for if a current be supposed to exist in the connecting wire of a battery from the zinc to the copper, it will be in each connected pair of plates from the copper to the zinc, and the wire I have used is that connection between the two plates of one pair." What all this means I do not pretend to understand, but I presume from its name that the calorimotor gave such a large current that it made the wires hot.

In view of the discussion which has taken place in recent years concerning the relative merits of the spellings "starter" and "startor," "converter" and "convertor," etc., it is interesting to note that Faraday writes both "calorimotor" and "calorimoter" indiscriminately.

In their first report, issued in 1862, the British Association committee refer to "a battery or rheomotor of unit electromotive force." (Greek "rhein" = to flow.)

Another rather unexpected word occurs in a letter of 1832 from Nobili of Florence, published in the *Philosophical Magazine*, in which he speaks of "hydroelectric currents"; he says: "two (galvanometer) systems may be adopted to obtain maximum effects, the one for hydroelectric currents, the other for thermoelectric currents. The galvanometer of my thermo-multiplicator is of the latter kind and precisely that which is best in the present researches (reversing a coil in the earth's field). The reason will be evident by observing that the new currents of Faraday are entirely developed in metallic circuits, like the thermo-electricity of Dr. Seebeck, and that also like those of thermo-electricity they pass with difficulty through humid conductors." Hydroelectric currents were obviously those produced by primary cells. Nobili regarded the latter as high-voltage generators which required high-resistance galvanometers for their effective detection—as undoubtedly they were when compared with thermo-couples and earth-inductors. That this was the recognized terminology is evident from the footnote which the editor (Poggendorff) added to Ohm's first communication in 1825, viz.: "It is to be hoped that the author will repeat his experiments with the thermo-electric chain, as the action with this is much steadier than with the hydro-electric chain and consequently lends itself to more accurate measurement."

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* "Electrical Papers," vol. 2, p. 25.

To Faraday "ordinary" or "common" electricity was that obtained from a frictional machine; it is always so called in his "Experimental Researches." In 1833 he tabulates the five kinds of electricity as follows:—voltaic, common, magneto, thermo, and animal; the object of the paper being to show that they are all identical in nature. Volta, in a letter to a friend in England in 1792, i.e. 8 years before he invented the voltaic pile, compares *électricité animale* with *électricité commune*. One has to remember that before 1831 the only machine for generating electricity was a frictional machine, and in 1832 Faraday says: "the revolving copper plate becomes thus a new electrical machine and curious results arise on comparing it with the common machine; in the one the plate is of the best non-conducting substance; in the other it is the most perfect conductor."

Faraday could not conceive that a conducting wire, running side by side with another wire in which a large current was flowing, could be in its normal state. Since something happened in it when the neighbouring current was started and again in the reverse direction when the neighbouring current ceased, Faraday felt that the material of the conductor must be in some special state while the neighbouring current was flowing steadily. He therefore invented a term and spoke of the conductor as being in an "electrotonic state." Although he gave up the idea in after years, he occasionally showed signs of nursing it at the back of his mind. In our modern phraseology we should say that the conductor was "linked with a magnetic flux." In the 1895 British Association report we read of "total induction" in a magnetic circuit, the same quantity being also called "total flux," "total lines," "electromagnetic momentum" and "electrotonic state;" it was proposed that its practical unit (10^8 C.G.S. units) should be called a "weber." This was, I think, the last appearance of the term "electrotonic state."

Although Faraday uses the term "current," he says: "I am giving no opinion respecting the nature of the electric current now, and though I speak of the current as proceeding from the parts which are positive to those that are negative it is merely in accordance with the conventional agreement entered into by scientific men." In another place he says "that what we call the electric current may perhaps best be conceived of as an axis of power having contrary forces, exactly equal in amount in contrary directions." This reminds one of Oersted's quaint phraseology in describing his great discovery; he says: "to the effect which takes place in the conductor and in the surrounding space we shall give the name of the 'conflict of electricity' and from the preceding facts we may likewise conclude that this conflict performs circles." Dr. Wollaston in 1821 called the magnetism produced by a current "vertiginous magnetism."

In another place Faraday says: "By current I mean anything progressive, whether it be a fluid of electricity or two fluids moving in opposite directions, or merely vibrations, or speaking still more generally, progressive forces." He evidently had a very open mind on what was happening in the wire.

Although he apparently did not know the word "resistance" in 1831, he used the reciprocal conception and spoke of good and bad conductors and of the "conducting power of a circuit."

He used the term "tension" for what we should now call the "potential difference." He says: "that ordinary electricity is discharged by points with facility through air is due to its high tension." The use of the term still persists in the distinction between high-tension and low-tension currents, but is not now used in any accurate quantitative sense. It is interesting to note that in their 1863 report the British Association committee stated that they had intentionally avoided the use of this term because it had been somewhat loosely used by various writers. In 1827 Ohm referred to "electric tension," that is, difference in electric condition, and in another place to "electric tension, or difference of the bodies." He also used "electric force" and "electroscopic force," the latter because, to define the electrical states of different points, he imagined a proof-plane brought into contact and then tested on an electroscope.

Almost immediately on learning of Oersted's discovery, Ampère in October 1820 proposed an electromagnetic telegraph with a separate wire for each letter and he used the word *galvanomètre* to describe the deflected needles; he also introduced the term *astatique* and in the following year (1821) proposed the well-known astatic arrangement of two needles.

In 1834 Faraday introduced and explained many of the terms now universally employed in electro-chemistry. He had consulted Dr. Whewell of Cambridge, a philological authority, and between them they invented "electrolysis," "electrolytic," "electrodes," "anode," "cathode," "ions," "anions," "cations," and "voltameter." This last was called a "volta-electrometer" in 1834, but in Faraday's 1838 paper it appears in the shortened form.

A letter from Whewell to Faraday in 1837 contains some of the words which might have been inflicted on us. As the letter is very interesting I quote it in full:—"I am always glad to hear of the progress of your researches and never the less so because they require the fabrication of a new word or two. Such a coinage has always taken place at the great epochs of discovery; like the medals struck at the beginning of a new reign; or rather like the change of currency produced by the accession of a new sovereign; for their value and influence consists in their coming into common circulation. I am not sure that I understand the views which you are at present bringing into shape sufficiently well to suggest any such terms as you think you want. However, by way of beginning such a discussion, I would ask you whether you want abstract terms to denote the different and related conditions of the body which exercises and the body which suffers induction? For though both are active and both passive it may still be convenient to suppose a certain ascendancy on one side. If so, would two such words as 'inductricity" and 'inducteity' answer your purpose? They are not very monstrous in their form and are sufficiently distinct. And if you want the corresponding adjectives you may call the one the 'inductric' and the other the 'inducteous' body. This last word is rather a startling one, but if such relations are to be expressed, terminations are a good artifice, as we see in chemistry, and I have no doubt if you give the world facts and laws which are better expressed with than without such solecisms, they will soon accommodate to the phrases, as they have often done to worse ones. But I am rather in the dark as to whether this is the kind of relation which you want to indicate. . . . I do not see my way any better as to the other terms, for I do not catch your objection to 'current' which appears to me to be capable of jogging on very well from 'cathode' to 'anode' or vice versa. As for positive and negative, I do not see why 'cathodic' and 'anodic' should not be used, if they will do the service you want of them."

The word "diamagnetic" was introduced by Faraday to designate a non-magnetic material, just as a "dielectric" was a non-conducting material; thus in 1845 he says: "By a 'diamagnetic' I mean a body through which lines of magnetic force are passing and which does not by their action assume the usual magnetic state of iron or lodestone." However, in 1850 he suggested to Whewell that "magnetic" should not be used as the opposite of "diamagnetic" but that "magnetic" should be general and include all the phenomena; he proposed "ferromagnetic" as the opposite of "diamagnetic," but Whewell pointed out that "ferro" was Latin and "dia" Greek, and suggested "paramagnetic" for those materials that place themselves lengthwise or parallel to the magnetic field. The word "diamagnetic" was then used to designate those bodies which are less permeable than a vacuum and which consequently set themselves transverse to the field. The fact that some bodies are diamagnetic was one of Faraday's great discoveries. I do not know whether Faraday consulted Whewell before coining the word "dielectric" in 1837. It was at this time that he introduced the term "specific inductive capacity."

Although Faraday invented the term "lines of force" and devoted much time to their elucidation, some of his statements concerning them are difficult to understand. For example, in Series 27 of the "Experimental Researches," written in 1851, he says: "There exist lines of force within the magnet of the same nature as those without. What is more, they are exactly equal in amount to those without. . . . Every line of force, therefore, at whatever distance it may be taken from the magnet, must be considered as a closed circuit, passing in some part of its course through the magnet, and having an equal amount of force in every part of its course." As the lines are equal in amount in the steel and in the air, they are lines of induction (B) and not lines of force (H); in this connection it is interesting to note that in an appreciation of Faraday in a recent number* of the *Elektrotechnische Zeitschrift*, Prof. Görges of Dresden says: "lines of force, or as we should say to-day, lines of induction." Moreover, the meaning of the concluding sentence can only be made clear by assuming that Faraday was thinking of a tube of induction and of the integral of the magnetic induction over the cross-section of the tube, since this is the only quantity that is constant in amount in every part of its course.

This example serves to show how difficult it sometimes is to discover from his writings exactly what his conceptions were; this is due partly to the fact that he was exploring entirely new fields, feeling his way and inventing terminology as he progressed, and partly to the fact that he was not mathematical and did not attempt to crystallize his ideas into formulæ.

I do not think that Faraday ever used the term "potential difference"; once in 1840 he speaks of the "electromotive force" of contact in connection with the voltaic pile, but apart from this he does not appear to have used the conception of e.m.f. Even as late as 1852 in a paper entitled "On the employment of the induced magneto-electric current as a test and measure of magnetic forces," he speaks of induced currents and thermo currents and of the application of Ohm's law, but it is very surprising that in a long paper with many numerical results and much discussion he never once mentions electromotive force. To him it was the source of the power of a voltaic cell, but in a coil or circuit the variations of the magnetic flux induced the current directly without the intermediate conception of an electromotive force.

The use of the "resistance" of a conductor rather than its reciprocal, the "conductance," seems to date from about this time; for although a paper in the *Proceedings of the Royal Society* for 1859 on the effect of pressure on electric conductibility in metallic wires contains no mention of resistance, but always refers to the conducting power of the wire, a name for the unit of resistance (but not for any unit of conductance) was suggested in a paper read at the 1861 British Association meeting. The first report of the British Association committee issued in 1862, however, generally refers to the "conducting power" of a resistance coil. Although Ohm did not use the word "resistance" in his classical paper of 1827, he used the conception, for he says that the current is inversely proportional to the sum of the equivalent lengths of the various portions of the circuit; the equivalent length being proportional to the real length divided by the product of the cross-section and the conductivity of the material. In 1831 he actually speaks of the "resistance" of the conductor ("Leitungswiderstand").

In the *Proceedings of the Royal Society* for 1859 there is a reference to "electromotive power," but in the following volume (1860) there are two papers in which Sir William Thomson uses the expression "electromotive force," which is really less accurate than the former since the magnitude to be defined is equal to the energy involved in the transfer of unit quantity of electricity, or to the power involved in the steady passage of unit current.

In a footnote to a paper in the *Proceedings of the Royal Society* for 1861, Sir William Thomson writes: "I have given the name of 'Wheatstone's Balance' to the beautiful arrangement first invented by Professor Wheatstone and called by himself a 'differential resistance measurer.' It is frequently called 'Wheatstone's Bridge,' especially by German writers. It is sometimes also, but most falsely, called 'Wheatstone's Parallelogram.' "

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* *Elektrotechnische Zeitschrift*, 1931, vol. 52, p. 1105.

The demand for distinctive and convenient names for the various electric units came, as might be expected, from the practical men, from those who were engaged in the design and calculation of telegraph cables. They found it very inconvenient to express their measurements in so many units of resistance or units of current, and at the British Association meeting at Manchester in 1861 Charles Bright and Latimer Clark read a paper in which the following names were suggested for the principal electrical units:—" galvat " for current; " ohmad " for electromotive force; " farad " for quantity; and " volt " for resistance. It was this paper that led to the appointment of the celebrated Electrical Standards Committee of the British Association, which after 6 years of strenuous work produced the system of units now adopted internationally, although not with exactly the same names. The word " megohm " appears in an appendix to the report of 1867, from which it also appears that the " farad " was expected to do duty for both quantity and capacitance, for Fleeming Jenkin says: " This practical series of units is that which in the opinion of Mr. Latimer Clark and myself is best adapted for practical use in telegraphy. Mr. Clark calls the unit of quantity thus defined (10^{-8}) 'one Farad,' and similarly says that the unit of capacity has a capacity of 'one Farad,' it being understood that this is the capacity when charged with unit electromotive force (10^{-5})." After all, a quart is not only a measure of quantity of a liquid, but also of the capacity of the jug into which it is poured, so that it is not surprising that Latimer Clark considered one unit enough for the two purposes. In 1873 he wrote*: " The measure of quantity is the same as that of electrostatic capacity and in practice generally receives the same name, although it has been sometimes called the 'Weber;' the Weber or Farad quantity is equal to 10^{-2} absolute units. Electrical currents are defined as currents of so many farads per second. In this system, the volt electromotive force through the ohm resistance produces the unit current of one farad per second."

As an indication of the confusion which was removed largely owing to the work of the British Association committee, it may be noted that their report for the year 1864 contains a table of the relative values of 14 different units of resistance in use at the time, one of them being the " British Association unit or Ohmad." Most of them were merely the resistances of wires of arbitrarily-chosen lengths and diameters.

The following quotation from a paper by Sabine in the first volume of the *Journal*† is interesting; hardly a word of it agrees with our present nomenclature. " A condenser is an induction apparatus so arranged that when charged to a given potential its electrostatic capacity can be suddenly decreased (generally by increasing the distance between its plates) and thus the tension of its charge proportionately increased. An accumulator, on the other hand, is an induction apparatus which only collects a charge of electricity. A Leyden jar is therefore an accumulator and not a condenser. . . . By inductive resistance is understood that quality of a dielectric in virtue of which it obstructs the complete polarization of its atoms, by a given difference of potential between its sides. The reciprocal of the inductive resistance of a body is what is called its 'inductive capacity.' . . . I find it convenient to express the specific inductive capacity of any insulating material in terms of the quantity of electricity which a plate one square foot coated-surface and one thousandth of an inch (or one mil) thickness is capable of containing when the inductive surfaces have a difference of potential of one volt. The unit of measurement by which the quantity of electricity thus contained is measured is called a micro-weber, and the capacity is then expressed in what are called micro-farads." Sabine evidently did not agree with Latimer Clark and Fleeming Jenkin that the same name would serve for both quantity and capacity.

The word " potential " which had been introduced originally in connection with the force of gravity, was first applied to electric fields by G. Green, and the British Association committee said in their 1863 report that " it is now coming into extensive use, but is perhaps less generally understood than any other electrical term." Kelvin had used it and defined it in a paper read before the British Association in 1852. In his 1827 paper Ohm set up ordinates proportional to the " electroscopic force " at every point of his circuit, and defined the " fall " (" Gefälle ") as the difference between two ordinates separated by unit distance. He stated clearly that the current was proportional to this gradient. He actually used the word " *Abdachung*," which is equivalent to " slope."

A long appendix to the 1863 report written by Clerk Maxwell and Fleeming Jenkin did much to crystallize electrical nomenclature; they speak always of the " strength " of a current and not of its " intensity "; they define the " electric force " at a point (which Maxwell sometimes calls " electromotive intensity "), " electric induction " (which he also called " displacement ") and " magnetic induction." This first committee was dissolved in 1870; in their last report, the " accumulators " of their earlier reports had become " condensers," but they had reverted entirely to the " intensity " of the current. It was two years later, however, that Sabine, as we have seen, wished to maintain a distinction between accumulators and condensers.

The committee was re-appointed in 1880, and in their first report (1881) they state that " the present usage is that a resistance of 10^9 c.g.s. units is called an 'Ohm'; an electromotive force of 10^8 c.g.s. units is called a 'Volt'; and the current produced by a 'Volt' acting through an 'Ohm' is called a 'Weber.' " It is interesting to notice that, although the name Weber had been commonly used for the unit of current for many years—so that Preece was able to report in 1873:* " I find that the practice of recording the strengths of currents in Webers has been in regular use for some years in the military school of Chatham "—the first International Congress of Electricians held in Paris in 1881 replaced it by the name of a French scientist, Ampère. Again, although Heaviside had advocated in 1885 the giving of a name to the practical unit of inductance and had used both "tom" and "mac," the third international congress held at Paris in 1889 decided to call it a "quadrant," but the fourth congress held at Chicago in 1893 replaced this by the name of an American scientist, Henry. More recently, on the first occasion that the international congress was held in Scandinavia, the confusion which had arisen owing to the use of the term "gauss" for the units of both H and B was removed by giving the name of a Danish scientist, Oersted, to the former unit. All of which tends to show that in the naming of units, as in other fields of international rivalry, the home team have a certain advantage.

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* *Journal of the Society of Telegraph Engineers*, vol. 7, p. 86.
† *Ibid.*, 1872, vol. 1, p. 245.

* *Journal of the Society of Telegraph Engineers*, vol. 7, p. 84.

Of all the scientists whose names have been proposed for the designation of units, the most unfortunate is Weber. The British Association committee originally proposed that the unit of quantity should be the "weber," and the unit of current, now called the "ampere," was to have been called a "weber per second;" but the "per second" was dropped, and currents were measured in webers down to 1881 when the unit was replaced by the ampere at the Paris Congress. The 1889 Paris Congress recommended giving names to the "practical" units of flux and flux density, i.e. to 10^8 C.G.S. units, and suggested "maxwell" and "weber" respectively. The 1891 Frankfort Congress recommended the name "gauss" for the practical unit of field intensity and "weber" for the unit of flux, but again no action was taken. In their 1895 report the British Association committee recommended for tentative adoption the following terminology:—

1. "That as a unit for magnetic field a hundred million c.g.s. lines be called a 'weber.' Hence the webers 'cut' by a closed wire circuit of n turns are equal to the quantity of electricity thereby impelled round that circuit multiplied by $1/n$ of its resistance in ohms."

2. "That the c.g.s. unit of magnetic potential or of magnetomotive force be called a 'gauss.' Hence the number of gausses round any closed curve linked on an electric circuit is equal to 1·2566 times the number of ampere-turns in this circuit."

In this same report it is recommended that the terminations "-ance" and "-ivity" or "-ility" should be used in the manner that has since become general.

In discussing the decisions made at the Stockholm meeting in 1930, Blondel has urged that the practical unit of flux should be called the "weber" rather than the suggested "pramaxwell." As he points out, one calls 10^7 ergs a "joule" and not a "praerg."

Heaviside, writing soon after the Paris Congress, referred to the decision to apply the name "ampère" to the unit of current as a remarkable step. He objected to it as being too long and feared that it would be shortened to "amp," which he thought was not nice. His fears were well justified. "Better make it 'père,' said Heaviside, with a twinkle in his eye, "for was not Ampère the father of electrodynamics?" Writing in 1885, Heaviside advocated very short names such as "dyne" and "erg;" he not only suggested "mac," "bob," "tom" and "dick" as all being very good names for units, but pointed out with his characteristically subtle humour that if "mac" was given "max" for the plural it would have a wide national appeal. It is interesting to note that Heaviside really used "tom" as the practical unit of inductance for some years, and wrote of "millitoms" and "microtoms;" he hinted that he intended this as a compliment to Sir William Thomson. Later, in 1887, as a tribute to Maxwell, he suggested "mac" as the unit of inductance and pointed out that, if it was taken as 10^9 cm, "millimacs" would be wanted to avoid decimals. In 1893 the Chicago Congress adopted "henry" as the name for this unit, and Heaviside's "millitoms" and "millimacs" became "millihenries." It was in 1887 that Heaviside pointed out the need of practical instruments for measuring the inductance of coils "in terms of units of inductance—macs or millimacs," and suggested that such instruments should be called "inductometers." In the same year he introduced "attenuation" and "distortion" in solving transmission problems; "attenuation," he said, he found already in use by Lord Rayleigh and adopted it at once as the very thing he wanted; "distortion," on the other hand, he chose himself as preferable to "mutilation" and similar words.

The need for practical units of energy and power did not arise in connection with telegraphy, but became apparent as soon as electrical energy became an article of commerce. In the 1887 report of the British Association committee "it was resolved on the motion of Mr. Preece, seconded by Sir William Thomson, to recommend the adoption of the 'Watt' as the unit of power. The Watt is defined to be the work done per second by the ampere passing between two points between which the difference of electrical potential is one volt." It was in this 1887 report that the "coulomb" appeared for the first time, a French convention having suggested it for international consideration as a suitable name for the ampere-second. In the 1888 report "it was resolved on the motion of Mr. Preece to adopt the name 'Therm' for the gramme water degree Centigrade unit of heat. It was also agreed to adopt the name 'Joule' for 10^7 c.g.s. units of work . . . hence a power of one watt is one joule per second." In 1889 the committee reported that the Paris Electrical Congress had adopted the "watt" and the "joule" and had recommended that in industrial applications the power of machines should be expressed in "kilowatts" instead of in "horse-power." This same Paris Congress also adopted Heaviside's suggested "impedance." During 1895 and 1896 much correspondence and discussion took place concerning the unit of heat; among the names suggested were "Rowland," "Meyer," "Kelvin" and "Calor." In their 1896 report the Committee suggested the "calorie," which has met with universal acceptance.

Turning again to the magnetic units we find that, although it has not shared the fate of the "weber" in being ultimately banished from the cast, the "gauss" has played so many parts that one may be excused for being somewhat uncertain as to its present rôle. In the appendix to their 1895 report, the British Association committee discuss Heaviside's suggestion that the magnetomotive force be called the "gaussage" and that its C.G.S. unit be one "gauss"; they speak of the difference of magnetic potential between two points as the fall of "gausses" or the "gauss-fall" from A to B. "Intensity of magnetic force, or H, will be naturally expressed as gauss-fall per centimetre, or the gauss-gradient."

At the conclusion of the 1900 Paris Congress great confusion was caused by some of the delegates going away thinking that they had given the name gauss to the unit of magnetic induction (*B*), while others were under the impression that it had been given to the magnetic force (*H*). The confusion was really due to the failure to recognize the essential difference between *H* and *B*, and the necessity for giving names to each. This point had been strongly emphasized in the 1895 British Association report, which said: "That the essentially different quantities commonly called *H* and *B* should be carefully kept distinct, although their measures in air have been conventionally so arranged as to be numerically equal. *H* should not (strictly speaking) be expressed as so many lines per square centimetre; that mode of expression should be reserved for induction density *B*. *H* is the cause and should be thought of as the slope of magnetic potential; *B* is the effect. In a medium of so-called unit permeability the two quantities are numerically equal, but they should not be confounded, any more than the slope of electric potential, or electric intensity, should be thought of as identical with current-density even in a medium of unit conductivity. Now, as must often have been pointed out, the equation $B = H + 4\pi I$ is a barbarous one, involving as it does quantities of different dimensions. . . ."

Dr. Johnstone Stoney, who was a member of the committee, was in favour of interchanging the names "gauss" and "weber"—an ominous sign. Long before this, however, in 1882, Heaviside—in discussing a disagreement between Clausius and Maxwell as to the dimensions of a magnet pole—said: "the error appears to lie in the neglect of the distinction between magnetic force and magnetic induction."

The name "permeability" for the relation between the magnetic induction (*B*) and the magnetizing force (*H*) was originally suggested by Kelvin in 1872; he pointed out that it was analogous to the relation between heat flow and temperature gradient and between liquid flow and pressure gradient in a porous medium. Faraday had called it "the conducting power of a magnetic medium for lines of force." In 1886, however, Heaviside suggested* that "permeability" should be abolished and replaced by "inductivity," which would indicate its connection with magnetic induction and self and mutual inductance.

The muddle which ensued from the misunderstanding at the Paris Congress was cleared up by the International Electrotechnical Commission at Oslo in July 1930. It was decided that the C.G.S. unit of flux should remain a "maxwell," that the unit of flux density or induction (*B*) should be a "gauss," that the unit of magnetomotive force should be a "gilbert," and that the unit of magnetizing force (*H*) should be an "oersted"—a fitting recognition of the scientist who first discovered a connection between electricity and magnetism. As Prof. Kennelly† has said: "By far the most important result of the new I.E.C. resolutions is that, if followed, the indefiniteness and ambiguity which have often characterized the literature of the magnetic circuit, on questions of *H* and *B*, can be eliminated. The term gauss, for instance, can only be used for flux density *B*."

In 1926 the British Engineering Standards Association published a "Glossary of Terms used in Electrical Engineering,"* but unfortunately the sections dealing with the fundamental terms of electrical technology were very confused and in no way representative of generally-accepted usage. Cause and effect in magnetic and electric phenomena were so mixed up together that many of the definitions were unintelligible. If the Zoological Society invited a person to write a guide to the Zoo, not knowing that he had philosophic doubts as to the objective existence of, say, the rhinoceros and hippopotamus, the person would have three alternatives, apart from that of declining the task. He might keep his philosophic doubts to himself and describe the two animals from the point of view of his less enlightened brethren, or he might omit their names and all reference to them, or, finally, he might bestow their names upon some other animals, say, a variety of polar bear. The authors of the Glossary were in a somewhat analogous position. Most authorities assume that an electric force *E* acting on a dielectric produces an electric displacement *D*, and that a magnetizing or magnetic force *H* produces a magnetic induction *B*. The authors of the Glossary, having doubts about the existence of the electric displacement and of the magnetic induction, merged them into the forces that produce them and were left with these two widely-used terms on their hands. They adopted the second alternative in the case of displacement and omitted it entirely, but in the case of magnetic induction they adopted the third method, and bestowed the name on another quantity altogether, namely the total magnetic flux. This lack of discrimination between cause and effect prevails throughout these sections of the Glossary and leads to general confusion. For example, having defined electrostatic flux as the number of unit electrostatic tubes of force, so that one cannot distinguish between force and flux, they then define dielectric hysteresis as the lagging of the electrostatic flux behind the electric force producing it. Excitation is defined as the magnetizing force (symbol *H*) producing the flux in an electromagnet; coercive force is defined as the magnetomotive force required to annul the residual magnetism of a substance, and so on. As I have said on a previous occasion, such a production should not have been issued with the authority of the British Engineering Standards Association.

As an example of the confusion existing at the present time in the nomenclature of magnetic quantities, we might refer to the *Journal of Scientific Instruments* for April 1931, where a curve is stated to show the values of *B* for values of *H* from 0 to 0·5 gauss. The curve itself gives *H* in gilberts, the maximum being 0·08 gilbert, and *B* in gausses up to 5 000. What relation 0·5 gauss may bear to 0·08 gilbert, or what relation either of them may bear to the value of *H* in oersteds, the unit recommended by the International Electrotechnical Commission in 1930, is left to the reader's imagination. Another example occurs in a pamphlet on the physical properties of nickel-iron issued in July 1931 by the Mond Nickel Co.

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* *Electrician*, 1886, vol. 16, p. 271.
† *Transactions of the American I.E.E.*, 1931, vol. 50, p. 737.

* B.S.S. No. 205—1926.

Fig. 1 in this pamphlet gives the μ-H curves of several nickel alloys and Fig. 2 gives those of mumetal and commercial silicon iron for comparison, but in Fig. 1 the magnetizing force is given in gilberts per cm, whereas in Fig. 2 it is given in gausses. How is the average reader of a pamphlet on nickel to know that these are one and the same thing, and that they are both what we used to call "C.G.S. units," and what the Oslo Conference decided must in future be called "oersteds?" It is quite possible, moreover, that the next magnetization curve he comes across will be plotted to none of these but to ampere-turns per cm.

In 1886 Heaviside said: "if we pass to electric displacement, the analogue of magnetic induction (noting by the way that it had better not be called the 'electric induction,' on account of our already appropriating the word 'induction,' but be called 'displacement'), the existing terminology is extremely unsatisfactory." He then suggested altering the definition of specific inductive capacity, or, as he preferred to call it, "specific capacity," so that it would be the capacitance of a unit cube; this would entail hiding the 4π in the specific capacity, so that it would not intrude itself in the subsequent calculations of capacitance from the dimensions of the condenser.

He expressed his dislike of the adjectives "capacious" and "incapacious" and of the inverse noun "incapacity:" he also thought the word "capacity" rather objectionable as likely to give beginners entirely erroneous notions. His wishes have been largely met, for "capacitance" has largely replaced "capacity," and the adjective generally used is "capacitive"—although one often sees the strange word "capacitative." Fortunately the reciprocal has not been introduced, and we have not been threatened with "daraf" as the name of a unit.

Heaviside suggested "permittance" instead of "capacity," and "elastance" as its reciprocal. He drew up the following table:—

Flux	Force/Flux	Flux/Force	Force
Conduction current	Resistance	Conductance	Electric
	Resistivity	Conductivity	
Induction	Reluctance	Inductance	Magnetic
	Reluctivity	Inductivity	
Displacement	Elastance	Permittance	Electric
	Elastivity	Permittivity	

He invented the words "elastance" and "elastivity" to avoid having to say "electric elasticity," or run the danger of confusion with other elasticities. "Reluctance" and "reluctivity" were not in the original table; he invented them later so as to avoid the use of "magnetic resistance." It was in this same paper that he suggested the word "impedance" for the ratio of the amplitude of the impressed electromotive force to that of the current. He also suggested that a coil used for impeding might be called an "impeder."

In 1904 the British Association committee considered and reported on two suggestions put forward by Prof. Kennelly. The first was that the absolute units should have the same names as the corresponding practical units but with the prefix "abs" or "abstat" depending on whether the electromagnetic or the electrostatic absolute system was adopted. The committee disagreed with any prefixes which did not bear definite numerical signification. Prof. Kennelly has, however, consistently adopted this plan himself in a slightly simplified form, and employs "abohms," "statfarads," etc. His second suggestion was the adoption of a systematic nomenclature for the magnetic units. Now although personal names had been given to the practical electrical units and not to the C.G.S. units, the committee, for reasons not stated, were in favour of basing any nomenclature on the C.G.S. magnetic units, but were of the opinion that a system of nomenclature was not called for. Moreover, the committee showed their disapproval of Prof. Kennelly's proposals by consistently mis-spelling his name. The Paris Congress had already in 1900 recommended the name "maxwell" for the C.G.S. unit of magnetic flux, and the British Association committee had in the same year adopted it, and had also adopted the gauss for the C.G.S. unit of magnetic field.

Prof. Kennelly has now carried his system of prefixes a step further, for he calls the practical magnetic units by the same name as the corresponding C.G.S. units but adds the prefix "pra" as an abbreviation of "practical." These units are still in an unsettled state, and although one can say with certainty that a "pramaxwell" is a magnetic flux of 10^8 C.G.S. units or that a "praline" is 10^8 lines, there is no such certainty about the meaning of a "praoersted" or of a "pragilbert." The obvious practical unit of electromotive force is the ampere-turn, or simply the ampere, without any $4\pi/10$, and little is gained by calling it a "pragilbert." The giving of names to all the C.G.S. magnetic units appears to have introduced much unnecessary complication.

Some dissatisfaction has been expressed over the mutilation of the names of great scientists in making names for units. "Farad" and "volt" are two examples, but the most undignified and ugly procedure is the reversal of a name to designate a reciprocal. The unit of conductance is a case in point, and in suggesting the name of Siemens for this unit the German National Committee protested against the use of the word "mho." In 1896 a leading French scientist suggested that the unit of permeance should be called the "arago"; he has lately suggested that the unit of its reciprocal, reluctance, should be given the horrible name "ogara." More recently an American has published a table in which the unit of reluctance is called a "yrneh."

A practice has grown up in Germany in recent years to refer to a frequency of 50 cycles per second as a frequency of 50 "hertz," but, although it has been brought before the International Electrotechnical Commission, the "hertz" has not been officially recommended as the unit of frequency. One of the most recent additions to electrical nomenclature is the "bel," after Graham Bell, as the unit of attenuation or amplification of a signal in passing through any line or apparatus. The name of "neper," after the inventor of logarithms, has also been used for the same purpose. Either is preferable to "transmission units," which is invariably shortened to "T.U."

There are many units to which I have not been able to refer in the time available, and no reference has been made to illumination and other subjects closely allied to electrical engineering, but I have attempted to give a general outline of the evolution during the last hundred years of the nomenclature of the main fundamental conceptions of electrical engineering.

NORTH-WESTERN CENTRE: CHAIRMAN'S ADDRESS

By L. ROMERO, Member.

(*Address delivered at* MANCHESTER, *20th October*, 1931.)

I propose to attempt first a very brief review of the present state of development of the principal uses of heavy-current electricity in this country, indicating what appear to me to be the most important matters on which attention should be concentrated for the purpose of facilitating development; then to refer to the measures of rationalization which electricity supply is undergoing, and finally to draw attention to certain remoter but very important effects of the development of electrical engineering on the life of the community.

Among the uses of electricity I will mention lighting first, because it is the basis on which the business of the public supply of electricity has been built up.

For lighting, electricity is in process of occupying the whole field, and other means of artificial illumination only linger on to-day as precarious survivors from the pre-electric age. The change-over to electric lighting in our cities is going on at a faster rate each year, and the present position is that this change-over is almost complete for all types of premises except dwelling-houses. In the majority of our cities a very large number of the smaller and older dwelling-houses are still without electricity, and while there is no doubt that the great majority of these could be changed-over in a very few years by the adoption of an assisted wiring scheme with prepayment meters and a high rate per unit to pay for the wiring, I believe that the majority of supply engineers with d.c. networks to change over to alternating current are content with the present rate of progress in connecting new d.c. consumers, as it is obvious that the cost of the change-over would be correspondingly increased by any increase in this rate of connection of new d.c. consumers.

Even with this objection out of the way, however, I should not feel much enthusiasm for the prepayment-meter assisted wiring scheme, as the high rate per unit charged under such schemes is a very bad introduction for electricity to new consumers, and is bound to limit its use to lighting only, and to as little of that as possible.

Whether or not this particular means of attracting small lighting consumers is adopted, I think that the next 10 to 15 years will see practically all non-electric premises in our towns changed over to electricity, at least for lighting. There will then perhaps still remain to be won a certain amount of street lighting, that last ditch of the old regime. I am told that in some Continental cities in which electricity is practically universal for lighting all classes of buildings both inside and out, older forms of illumination are still used to a considerable extent for lighting the streets. This is curious, because it is in the open air that electricity has, by its indifference to wind and frost, very great—if not its greatest—advantages over other forms of lighting.

Alongside this increase in the use of electricity for lighting owing to its inevitable replacement of other lighting agents, there has also been a steady increase due to growth in the standard of illumination. This increase in illumination values has been caused largely by the great improvements which have been made in the efficiency of electric lamps, by the reductions in the price of electricity and, in its more extreme forms, by the competitive spirit of modern retail business in its efforts to attract the attention of the public. It would seem that intensity of illumination cannot be increased very much beyond that now employed in some shop windows, but no doubt the levelling-up process will go on for many years to come. A fairly rapid increase is also taking place in some areas in the use of electric light for advertising signs.

INDUSTRIAL POWER.

Electricity is as supreme for industrial power as it is for lighting, and the electrification of industry—already at an advanced stage—goes on apace.

The present exceptionally severe and prolonged trade depression has naturally had a considerable effect on the amount of electrical energy used for industrial-power purposes. It is, however, consoling to reflect that one of the most obvious factors in the rationalization of industry, which has been speeded-up by the trade depression, must be the efficient application of electric power, and when trade again becomes good an extremely large increase in the units for industrial power will be manifested.

Room or Building Heating.

The use of electricity for this purpose is developing at present chiefly in domestic premises, the reasons being first the relatively low price per unit generally available, and secondly the intermittent use which is made of dining-rooms, bathrooms, bedrooms, etc., as compared with the continuous use of nearly all rooms in business and industrial premises; electricity being, of course, much more competitive with coal when heat is only required intermittently for relatively short periods.

Electric fires are being installed in very large numbers in domestic premises every winter, and in the normal course of our English climate they are used intermittently and with a fairly high diversity factor for about 9 months of the year. The load thus provided is in my opinion quite a satisfactory addition to the system load as a whole, but it must be admitted that electric fires do constitute a source of trouble to supply engineers when our weather at very rare intervals turns arctic for two or three weeks on end. Under these conditions there is a tendency for everyone to switch their fires on and leave them on, largely with the idea of preventing the freezing of water-pipes. Diversity factor almost disappears with this form of use, and some of our mains and transformers have to carry very much greater loads than ever before.

The only satisfactory way of guarding against damage to plant and failure of supply under these conditions is to keep in reserve a substantial margin of copper over and above that required to meet normal peak-load conditions. An ample provision of copper is also very desirable for two other reasons, first for its beneficial effect on the voltage regulation of the system, and secondly because it proves extremely useful on the rare occasions when breakdowns occur.

The percentage increase in maximum load on the national "grid" due to such exceptional weather conditions would, of course, be much smaller than on parts of individual undertakings' distributing systems, and it will probably not be necessary to take such a contingency into account in determining the amount of spare generating plant required in our "selected" stations.

Cooking.

Cooking by electricity is a proved success to the user from every point of view and is making rapid progress wherever facilities for hiring are offered to consumers.

Many supply undertakings are subsidizing the development of this load by supplying cookers on hire at a substantial loss. This loss is very much less than it was a few years ago owing to the great reduction in maintenance costs which has been brought about by improvements in design and manufacture, but it is still too large to be considered satisfactory. Manufacturers have recently reduced their prices, and no efforts should be spared to improve methods of production still further so that prices may be further reduced, as it is only by this means that a very extensive use of electric cookers by the poorer classes can be brought about.

I should like to make a plea here for the supplying of cookers, water-heaters and other domestic appliances to consumers on simple hire. Municipal electricity undertakings at any rate exist solely for the purpose of rendering service to the community, and I maintain that very good service and very great economy are rendered to the community as a whole by the supply and maintenance of apparatus of this kind by one central authority highly organized for prompt and economical maintenance service.

Water-Heating.

I know from several years' personal experience that an ever-ready supply of very hot water is one of the greatest boons which electricity has so far made available for the home, and for this reason I believe that domestic water-heating is destined to become one of the more important forms of load on our power stations in the future. I visualize the time, perhaps not very far distant, when a majority, at any rate of our suburban houses, will use electricity for water-heating either exclusively or in combination with the coal fire. This will mean that in the warmer weather which is supposed to visit us every summer these houses will burn no coal at all, much to the comfort and increased leisure of their inmates and much to the improvement of the general atmosphere and of the health of town dwellers.

The development of electric water-heating, by its beneficial effect on system load factors, will also tend to reduce the cost of electricity and therefore to extend its uses in other directions.

In my opinion three main conditions must be present if electric water-heating is to be developed rapidly and introduced into the homes of the relatively poor as well as into the homes of the richer classes. These conditions are:—(*a*) A fairly low rate per unit; (*b*) facilities for the hire of apparatus at low rates; (*c*) vigorous propaganda.

Industrial Heating.

The use of electricity for the application of heat in manufacturing processes opens up a wide field for development which hitherto has not been very much cultivated. Electricity is ideal for this purpose, first because it produces heat without any objectionable by-products, and secondly because it can be applied exactly where it is needed and temperature can be controlled with the greatest accuracy.

I am glad to say that manufacturers now appear to be paying a good deal more attention than formerly to the advantages of using electricity for this purpose, and a number of interesting installations are being put in or are projected in this district.

Transport.

The position regarding transport may be described as mixed. Where the vehicles to be propelled have to run on rails, the use of electricity is being slowly but steadily extended, and the complete electrification of our railways would now appear to be almost assured, the only matter in doubt being the time of the conversion. On the other hand, for street and road traction there is a strong tendency to abolish rails in favour of pneumatic tyres, and while we may, as electrical engineers, regret the immediate effects of this tendency, as members of the community we must, I think, welcome the change.

Unfortunately, the change from rail to pneumatictyred vehicles has up to now in the majority of cases been a change from electric trams to petrol buses, although the advantages of the electric trolley-bus for urban passenger service are very considerable. They may be briefly stated as:—(*a*) Relatively high average speeds where frequent stops are employed; (*b*) freedom from noise of gears and smell of fumes; (*c*) freedom from fire risk; (*d*) low operation and maintenance costs; (*e*) utilization of the plant, cables and, with additions, the overhead equipment already installed for the trams; (*f*) power derived from British coal instead of from imported petrol. The disadvantages are:—(*a*) The buses can only operate on equipped routes; (*b*) the buses cannot pass each other except by removing the trolley of one vehicle. The first of these disadvantages has very little weight, as bus routes in towns are fixed and definite in any case, and the second is, in my opinion, much outweighed by the many advantages of the trolley-bus.

I believe that the principal reason why more trolley-buses have not been used is that it is much easier to introduce petrol buses, a few of which can be purchased and tried out without the careful planning and organizing which must be necessary when a change is made from trams to trolley-buses. The majority of tramway managers have taken the line of least resistance, viz. petrol buses, but it is to be hoped that they may be persuaded before it is too late that the long view is the right view, and that no thought or trouble should be spared to obtain the best and most economical transport system possible.

Rationalization of Electricity Supply.

The business of electricity supply in our country is being rationalized in a number of important ways. I suppose one must give first place to the rationalization of generation by the Central Electricity Board with the aid of the national "grid." We have heard a great deal of criticism of this scheme and there is no doubt that many difficulties, both technical and financial, have still to be overcome; but I, for one, am a firm believer in the soundness of the general idea, and I think we should be proud that England has been the first country to introduce such a comprehensive plan. If we could have more wise planning in other fields on a national and international scale, we might avoid in the future many of the troubles we are going through at present.

The matter next in importance, if not the most important of all, is the standardization of the voltages at which consumers are supplied, and it is gratifying to know that this highly desirable change is being vigorously pursued in our own area.

Next in importance comes the change-over of consumers' supplies from direct to alternating current, undertaken at considerable cost for the sake of the ultimate economies which it will effect in the supply and use of electrical energy. This change is also being extensively carried out in our north-western area, and already some supply undertakings have either completed the change-over or can see the end of it a measurable distance ahead.

The complete change-over of all consumers to alternating current which is now being carried out by many undertakings was probably hardly contemplated by any of them when a.c. supply to consumers was first introduced, generally as a result of the change-over from direct to alternating current in generation. What happened in the case of one undertaking, which is probably typical of many, was that at first an a.c. supply was only given to new large power consumers; then a start was made with changing-over in order to avoid expenditure on additional d.c. converting plant and mains; and finally it was foreseen that as the change-over had been carried so far it would have to be completed sooner or later both for the sake of standardization and because a demand for alternating current was beginning to arise amongst d.c. consumers, especially for radio apparatus. Once a change of this sort has been decided on, it is obvious that the more quickly it is carried out the less it will cost, as there will be fewer consumers to change over.

The standardization of frequency throughout the country at 50 cycles per sec. is being undertaken by the Central Electricity Board at very heavy cost, which has to be borne by the supply industry, the standard-frequency members of which naturally do not feel very happy at being forced to pay for other people's heterodoxy. From the national point of view, however, this standardization is probably right, and the critics would no doubt be silent if only someone else had to pay.

All the measures of rationalization which I have enumerated will amount in sum to a very considerable improvement in the business of supplying the nation's needs in the way of electricity.

There is very general agreement that electricity tariffs should also be rationalized in the direction of standardization, but the difficulties in the way of altering existing tariffs are very considerable, and progress of this kind will probably continue to be slow unless it is found possible to impose a standard form of tariff by legislation. If such a task is attempted it is to be hoped that the need for making two-part tariffs compulsory for the consumer—instead of optional, as at present—will not be lost sight of. The present system allows the short-hour consumer to obtain his supply at considerably under cost, to the detriment of the long-hour user. Other directions in which more standardization would probably prove beneficial are reductions in the number of standard sizes of cable and in the number of standard meter capacities.

Electricity and Evolution.

The fact that we all have to earn our living by electrical engineering would be considered by many to be a sufficient incentive to us not only to do our best in our individual jobs, but also to do all in our power for the growth and advancement of our profession. This is probably quite true, but it is also true that good work in any field is only done by those who are keenly interested in the work for its own sake and who feel a strong desire to see it grow and develop under their direction. This interest and this desire constitute the conditions under which all good work is done, and I have no doubt that it is possible to be just as keen on, say, the work of discovering a new poison gas, the ultimate effect of which may be the destruction of half mankind, as on, say, cancer research, which may free mankind from its worst scourge.

Some of us, however, are so constituted as to derive an additional measure of satisfaction and happiness from the thought that our work, besides being interesting in itself, is also contributing to the well-being and development of mankind. I should like to say a few words here about the contributions which electricity is making to that end.

One thinks first of the wonderful improvements in communications which have been made by telegraphy, telephony and radio, and of the effect of those improvements in bringing the nations closer together, and in lessening international misunderstanding and rivalry. I will not, however, attempt to enumerate all the positive benefits which electricity brings, first because it would take too long, and secondly because there seems little need to emphasize them. All the comfort, the luxury, the convenience and the beauty which electricity brings in its train are already widely appreciated and are, of course, the principal reasons for the rapid progress which it is making. I should like to draw attention rather to a negative benefit which may prove in the long run to be the most important of all those benefits which electricity has to confer on mankind. I refer to the enormous saving in human labour which electricity, as a very important factor in modern science and industry, is bringing about.

We electrical engineers are in the vanguard of that industrial army of technicians and inventors which is constantly finding new ways, now in one department and now in another, of doing by machines, and automatically, things which formerly had to be done by men's hands. The process is one of gradual liberation for the performance of higher and more interesting work.

Biologists tell us that in the early stages of animal evolution, such processes as breathing and digestion which are now automatic and unconscious were the operations which occupied most of the time and attention of the organism. A somewhat similar but much more rapid change is now taking place in regard to the work of producing the food and other goods which are required for man's material welfare.

It is obvious that the progress of science, invention and industrial organization, in which electrical engineers have played a leading part, has already tremendously reduced the number of man-hours needed to produce almost every kind of goods and service, and this progress is still going on at a very rapid rate.

The enormous saving in labour so far made has been neutralized to a large extent by the improvement in the standard of living, and by the multiplication of man's wants which have run parallel with it. The saving in labour is also largely masked by the present bad state of organization of the social machine and the very inadequate distribution of the commodities produced, but it is, nevertheless, bound to go on steadily increasing the amount of leisure at the disposal of the great majority of men and women.

Man has been wisely called the "spiritual animal," and the ultimate test of the real value of all material progress will be its effect on man's spiritual stature.

We cannot be sure whether men will make good use of the increased leisure which we electrical engineers are giving them, but, undoubtedly, increased leisure is at any rate one of the essential conditions for the cultivation of man's higher faculties, and it should be a source of solid satisfaction to us to know that we are doing a very great deal towards ensuring that this essential condition will be present in the life of the community in the future.

NORTH MIDLAND CENTRE: CHAIRMAN'S ADDRESS

By R. G. WARD, Member.

(*Address delivered at* LEEDS, *27th October*, 1931.)

In addressing you this evening I feel that I cannot do better than take as my subject Michael Faraday.

Our Institution has taken a great part in the Faraday Centenary Celebrations both in London and, through the Local Centres, in the provinces. It is pleasing to note that in the North Midland Centre the Celebrations took the form of a great meeting at Hull, which was largely attended and altogether a most successful event. But I think we should be neglecting our duty in spite of all this if we allowed this event to pass without putting on record our recognition of the discoveries made by this great man.

It is now well known that Michael Faraday's father was a native of Clapham, a village in the West Riding of Yorkshire, and occupied the important position of the village blacksmith. This fact alone should be sufficient for the North Midland Centre to take a more than ordinarily keen interest in this great scientist. The famous electromagnetic discoveries made by him in 1831 have revolutionized the whole social life of the universe, and to-day scientific men of every country of the world are enlarging on the tremendous advantages which have been made possible by his invention. We are apt to forget from time to time what we really have gained by the persistent energies of Michael Faraday, and there may be a certain amount of indifference on the part of some to realize what has been the result of his work in this and other directions. It is therefore our duty to remind the general public of the great value of the exertions of this somewhat quiet and retiring personality.

Faraday was born in London in 1791, in humble circumstances, and was fatherless at the age of nine. He had very few, one might almost say no, educational advantages, and received from the local day school the rudiments of reading, writing and arithmetic.

At the age of thirteen he became errand boy to a bookseller, and one of his duties was to deliver the newspapers which were lent to the customers. He has told us that he was known as a "great questioner," and that on one occasion, while calling at a house in connection with his daily occupation, he thrust his head through some railings which separated it from the next, and began to ask himself whether he was on this side of the fence or the other, when the door opened and caused him to draw back so suddenly that his nose bled and he forgot all about his philosophic speculations. In after years he always showed great tenderness and thought for newspaper boys, remembering that he once occupied a similar position.

A year later he was apprenticed as a bookbinder, and never missed an opportunity of increasing his scientific knowledge, being permitted by his employer to read the books which were sent to be bound. It was at this stage that he was attracted to study electricity and commenced experimenting. Though greatly interested in science, he objected to the suggestion that he was a deep thinker or a precocious person, but considered himself a very lively and imaginative individual, though he tells us that facts were more important to him and saved him. For he could trust a fact, but always cross-examined an assertion. Through the kindness of a customer he was able to attend some lectures given by Sir Humphry Davy, and we find him with his foot on the first rung of the ladder which ultimately led him to fame. After various disappointments he became assistant to Sir Humphry and commenced his duties in the Royal Institution laboratory.

During the period when he was engaged at the Royal Institution, this young philosopher employed his spare time in original work. He attempted to harden steel and preserve it from rusting by an admixture of platinum and the nobler metals, but with no practical results beyond a few doubtful razors, which he presented to his friends. This was certainly an early, if not actually the first, attempt to produce the stainless steel of which we hear so much to-day and which is playing so important a part in every phase of life. But he appears to have been before his time in this direction, for we are told that he had great difficulty in procuring a refractory capable of standing the intense heat required in this process.

His persistent nature compelled him to continue his scientific experiments, and he was never weary of trying to make some new discovery in connection with electricity. It was with great interest that he studied what had been done by Ampère and Arago, both of whom had accomplished important work in connection with the science. Faraday eagerly devoured all the information he could procure of the doings of these pioneers, and after great thought and continued experiments he eventually attained his goal on the 29th August, 1831, when he detected the first sign of a current produced by magnetism.

On the 8th February, 1832, he made the following entry in his notebook: "This evening, at Woolwich, experimented with magnet, and for the first time got the magnetic spark itself. Connected ends of a helix into two general ends and then crossed the wires in such a way that a blow at A B would open them a little. Then bringing A B against the poles of a magnet, the ends were disjoined and bright sparks resulted." With points of charcoal on the wires, the tiny spark was visible as a small electric arc. This experiment was aptly described by Mr. Herbert Mayo in the following impromptu:—

" Around the magnet Faraday
Is sure that Volta's lightnings play:
But how to draw them from the wire?
He took the lesson from the heart:
'Tis when we meet, 'tis when we part,
Breaks forth the electric fire."

That this experiment, which was conducted with a small iron ring wound with copper wire and insulated in such a primitive manner, should have been the means of changing the outlook of the whole world, is almost beyond conception. Faraday most carefully produced with his own hands the electromagnets which were used in all his experiments, and some idea of the difficulties with which he had to contend may be gained when we learn that he had to prepare his own insulated wire. This piece of apparatus is now in the possession of the Royal Institution, and it was a fitting tribute that it was given the place of honour at the recent Centenary Exhibition. As one stood and gazed at it, it seemed marvellous that this should be the foundation of an industry of such importance and magnitude.

It was with these self-produced electromagnets and permanent magnets that he pursued his work which ultimately revealed to him the conditions which he called " lines of force." A better expression has never been found and it must be admitted that from this source we certainly obtain force.

Electrical engineers have some satisfaction in knowing that one widely-used expression—" farad," the unit of electrical capacitance—was derived from his name. It must not be forgotten, however, that his services in the world of chemistry were equally as important, and in a great number of instances have a bearing on matters electrical. In fact, they are sometimes so closely allied that one has difficulty in separating them.

Faraday refrained from applying his discoveries to practical purposes, and is said to have remarked: " I have rather been desirous of discovering new facts and new relations dependent on magneto-electric induction than of exalting the forces of those already obtained, being assured that the latter would find their full development hereafter." Doubtless all his hopes and imaginations have been realized to the full. The contrast is immense between the rough hand-made coils produced by Faraday and used by him in his experiments, and the colossal electrical machinery with which we are so familiar. The development has certainly been somewhat slow, and progress appears to have been almost at a standstill for a time. But in the last few decades the electrical engineer has utilized this discovery for the public benefit in no unmistakable manner, and on him rests a great responsibility to make still further progress in the future. When, however, one takes into consideration the vast body of capable men who belong to such an Institution as our own, one realizes that the matter of progress can be left in their hands with absolute safety.

We can be certain that all the electrical improvements of the present day are due to the intense thought and labour of Faraday, who has made it possible for us to have so many of the added comforts and facilities of modern life. To enumerate them all would be a difficult task, as they cover a vast area and extend from the massive electrical machinery of industry to the diminutive motor found in the home. There is not a single person whose conditions have not been improved by the developments of Faraday's work.

Many of those present have had the opportunity of witnessing the progress and growth of the science and are able to look back and note with pleasure what can be called a wonderful change in every phase of life. Power stations, the total output of which is many thousands of kilowatts, are working economically, and suggestions are being made for the installation of still larger plants. This is in great measure due to the municipal electrical engineer, who through his assiduity and foresight has done so much towards the advancement in the generation and distribution of electrical energy.

The Electricity (Supply) Act of 1926 and the creation of the Central Electricity Board were measures produced in the interests of the nation as a whole. Although they were rather belated, it is hoped and expected that they will be for the ultimate advantage of all. There is no doubt that the Board has done a great deal towards the extension of electrical distribution, and it should be the means of supplying a long-felt want.

Table of Working Costs.

Items	Cost per unit
Coal and other fuel	0·164d.
Oil, waste, water and stores ..	0·016d.
Wages of workmen	0·033d.
Repairs and maintenance ..	0·046d.
Rent, rates and taxes	0·034d.
Management expenses ..	0·017d.
Total	0·310d.

In the industrial world great progress has been made in the electrification of all the principal industrial undertakings. Throughout the country there are numerous instances of the untiring efforts on the part of those concerned with these electrical developments, and plants are in existence which are capable of giving quite a good account of their general working. It is not the good fortune of every industrial concern to have its own generating station, but a very large number are in existence and produce energy at quite an economical figure. It is pleasing to note that they have moved with the rest of the world in taking advantage of all the improvements which have from time to time been introduced. We find them generating and distributing e.h.t. alternating current as such, or else converting it into low-tension direct current for general-purpose work.

Turbo-generators of large capacity are generally used as prime movers. Occasionally internal-combustion engines are used where special circumstances make them a successful commercial undertaking. The adaptability of the steam turbine to more than one purpose, however, together with its high thermo-dynamic efficiency, is responsible for its general use in the generation of electrical energy. By the use of high-pressure superheated steam, higher efficiencies have been reached than were possible with the reciprocating engine; the turbine also gives the advantage of bleeding for feed-water heating or general process work.

The performances of this type of station are worthy of note, as will be seen from the table. The figures have been taken at random and thus give a general idea of present-day working costs.

The figures given in the table are for an ordinary weekly working load, including the week-end, when the load factor must of necessity introduce unsatisfactory conditions. From this it will readily be seen that the total price of 0·310d. per unit is quite comparable with that of a number of well-known stations, and is only surpassed by a few of the very large stations.

Boiler efficiencies of 80 per cent and over, together with an overall thermal efficiency of 15 per cent, have now become everyday practice, and efforts are being made to improve this figure. It should, however, be remembered that the individual conditions of every generating station differ and that each has its own economical efficiency, which it should be the concern of the engineer responsible to discover, for a high efficiency is not always economical, as the outlay involved in producing the former may counterbalance any saving which may accrue from the latter.

The above remarks apply to the power stations in this country in which steam is principally used. However, where there is a plentiful supply of gas which is suitable for use with internal-combustion engines, and which would otherwise be wasted, this method of generation is to be preferred.

The introduction of electricity into industry has changed the whole aspect of the situation. Perhaps in no sphere is the alteration more apparent than in the iron and steel works. As my activities have been connected in this direction for many years, a short résumé of the change which has taken place may be of interest.

Reciprocating engines with their numerous encumbrances have vanished and given place to the electric motor, and line shafts and belts have become a thing of the past.

The material is now handled by electric cranes, elevators or conveyors, and large machinery has been installed to meet these requirements. The machine tool has also been subjected to new conditions, as reorganization and re-designing have called for the use of motors of very large horse-power, which has a tendency to increase as time goes on. These improvements must have far-reaching results, for they lead one to think that the magnitude of the work which is being executed, and the speed with which it is completed, are far in advance of anything that was being achieved a few years ago.

The reciprocating engine has entirely lost its position in rolling-mill equipment, the motor which has replaced it being in every way more suitable and economic. These are sometimes rated in thousands of horse-power and are extremely efficient. Indeed, one could almost suggest that the rolling mills have entered upon a new era, for the developments which have taken place during recent years would provide sufficient data for an individual paper.

There have been greater developments in furnaces than in any other commercial apparatus. The arc furnace has done good work and is still doing it, and for certain processes it remains the best furnace for making steel. Naturally there has been a great advance in the arrangements for manipulating this type of furnace, and we seem to have arrived at a fixed figure in kWh per ton for melting. As the electric furnace depends for its existence on a cheap and abundant supply of current, it behoves the electrical engineer to be continually endeavouring to produce these conditions.

For some considerable period it has been recognized that some form of electric furnace is required to replace the crucible process of melting. After many unsuccessful attempts, finality appears to have been reached with the introduction of the high-frequency induction furnace. This has now passed the experimental stage and is coming into general use. Although at present the size of the furnace generally used is rather small, high-grade tool steel and small castings can be manufactured economically in large quantities, owing to the rapidity with which the heats are accomplished. As no extraneous material, such as the electrodes of an arc furnace, can come in contact with the metal which is being melted, the analysis of the material in the furnace remains unchanged, and steels of a complex nature can be melted and cast into ingots or moulds without any fear of contamination. Again, owing to the constant agitation of the contents of the furnace, alloy steels need no stirring or rabbling during the process of melting and casting. The frequency of the supply varies in accordance with the size and requirements of the furnace and covers a wide range extending from hundreds to tens of thousands per second. It is determined by the designer when preparing the data for the furnace and generator.

The period of melting and the power consumption vary with the class of material to be melted and the size of furnace. The time required for making a heat in a 5-cwt. furnace is approximately one hour with a consumption of 600–700 kWh per ton of steel. These figures may be taken as a fair average. The power for these furnaces is usually supplied by a motor-driven high-frequency generator, which, as a rule, has an efficiency of from 75 to 85 per cent. It is interesting to note that the high-frequency furnace is being used for refining, which adds materially to its advantages.

There appears to be an impression abroad that there are limitations to the size of this type of furnace. But this is not so, and I have no hesitation in repeating what I said in addressing the Sheffield Sub-Centre in 1928: "During recent years we have seen the introduction of the high-frequency furnace for steel-making, and very good reports have been received as to its behaviour. In fact I venture to say that there is a very wide future for this type of furnace, and I see no reason why there should be any limit to its dimensions and capacity. One has visions of seeing it predominate in steelworks, and one can imagine that at some time, if it does not take the place of the Siemens furnace, it will be a very serious competitor for the premier position."

Recent developments with the thermionic valve show that a considerable advance has been made and that we are on the threshold of great possibilities. To some it may be somewhat premature to suggest that it will shortly be used in connection with the high-frequency furnace, but the progress which has already been made is an indication that we are moving towards that end.

It was the good fortune of those who visited the Faraday Centenary Exhibition at the Albert Hall to see what can be easily claimed as the largest valve in the world. This was an entirely new one which had been manufactured for the Post Office for the purpose of telegraphic communication between this country and America. This piece of apparatus had been installed and was working prior to its being dispatched to London, and it successfully dealt with an input of 500 kW. When working, oil pumps are continually evacuating it, and a very high vacuum is maintained. The method of construction allows the internal parts which require renewal or repair to be quickly attended to, as the valve can be dismantled and re-erected in a few hours. It will be plainly seen that a thermionic valve of this description will play an important part in the future, for developments that are beyond the conception of the most optimistic will certainly take place as time goes on.

The complete change which has taken place in respect to the annealing and reheating furnaces since the application of electricity is worthy of note. It has necessitated the rearrangement of these types of furnaces, which are more economical, considerably cleaner than the old types, are automatically controlled and deal very expeditiously with the work which they are called upon to execute.

The general lighting of works has also been greatly improved, and gas has given place to the incandescent electric lamp, with wonderful results. The present lighting arrangements have greatly increased the output and quality of the work and reduced the risk of accident to the workmen.

I have tried briefly, but I fear somewhat inadequately, to show the connection between the present-day advantages and the discoveries of Michael Faraday. We owe to him a debt which can never be discharged, and it would be good for the world in general if we had in our midst a few men of similar calibre. By his unassuming, persistent and attractive manner, he has set a standard worth emulating. We are told that he was not a mathematician, and that he once boasted that he never made a mathematical calculation in his life except on one occasion when he turned the handle of a Babbage calculating machine. But his lucidity, his exquisite experimental skill, and the natural charm of his manner, combined to make him extraordinarily successful as a lecturer. Though so great a scientist, he had a lively sense of humour, and on one occasion when asked by a great politician what good his discovery was, he answered, with a twinkle: "Well, I think some day it may grow up into something you can tax." He was devoted to his wife, a lover of nature and mindful of his fellow creatures, and he reverently feared God. In short, he was one of the greatest personalities that has ever called himself an Englishman.

In concluding my address I feel I cannot do better than to quote the words of Sir William Bragg: "It is Faraday's public life that belongs to us: it is one of the possessions of the nation, one of the great treasures. It is not only that his work has had such far-reaching consequences that all the world is affected by what he did, not only that he made plain the intricate connections between electricity and magnetism so that we are in daily dependence upon these forces of Nature for the transfer of power and intelligence; it is not only that on his discoveries are now resting great British industries which are alive and are helping us through these difficult times. All these things are marvels, so that we are proud of our famous countryman. But we all love the man himself for his simplicity of faith and purpose, for the breadth of his vision and the humility of his thought, for his kindly generosity and for the light which he shed around. He thought first of the quality of what he gave, and only in the second place of that which he received in return. Could there be a nobler leading? Could there be any following more certain to bring us through times of depression and doubt to a triumphant ending?"

EAST MIDLAND SUB-CENTRE: CHAIRMAN'S ADDRESS

By F. Nicholls, Associate Member.

"DEVELOPMENT IN STEAM POWER PLANT PRACTICE."

(*Address delivered at* Loughborough, *6th October,* 1931.)

The opening of the present session is marked with particular significance in view of the fact that at the present time we are all, so far as is in our power, paying tribute to Michael Faraday, the founder of the vast industry that has evolved from his discoveries. His work outweighs in interest all the other beneficent contributions to our well-being and our very existence, which are consequent upon it. Some idea of its vast importance is conveyed to the mind by reflection upon the schemes in hand for the centralization of the country's electricity supply in order to co-ordinate, for the benefit of all, the numerous aids of which Faraday's work was the source. It is fitting that its true significance is fully appreciated and is being given effect to at the present time.

Consideration of the electrical fields that have opened out around us conveys to us the constant need for research work in all branches of electrical application, in order more effectively to extend existing services and to supply new sources of application in the most efficient and economical manner.

I propose to consider in this address the subject of development in steam power plant practice, and the results achieved thereby so far as they have come within the purview of my own experience. In choosing this subject I am fully aware that excellent papers have already been written regarding it. It would appear, therefore, that little remains to be said unless the subject be approached from a research point of view, or with the object of describing some new phenomena. I have no intention, however, of considering either of these aspects of the question. It appears to me to be preferable in an address of this sort to view the subject from a general as apart from a technical standpoint, and to consider also the part played by the electricity supply engineer in the general development that has taken place.

Development in any branch of engineering science is of absorbing interest to the professional engineer engaged therein. It provides him with an outlet whereby he can satisfy to the full extent the ambitions which developed during the years of his early training, and enables him to couple with it the results of his subsequent experience. There is also the factor of competition, all three combining to assist progress.

A survey of the wonders of modern engineering science at once impresses upon the mind how puny man is in relation to his achievements. By the process of development he has brought into being vast sources of energy and the means of creating energy, and an enormous system of mechanical aids to our existence is growing up around us. The process of development is continually progressive and consists in an unceasing endeavour to perfect existing instruments and to create new ones for the benefit of mankind.

Development, as applying particularly to steam power plant for providing a supply of electrical energy in keeping with other spheres of engineering, has also made remarkable strides; being a young industry, its commercial application and growth have taken place within the lifetime of many of us. Many of the more outstanding advances have been made within the last 20 years. A survey of this period, with its activities and the results achieved, at once conveys to us the ideas in the minds of those who accomplished them, and we for our part appreciate the satisfaction that is derived from solving any particular problem and obtaining the desired result.

It is in this branch of the industry perhaps more than in any other that the engineer is able to bring to bear his own personality. In other words, he is able to express the extent to which he is imbued with enthusiasm both by obtaining a high performance with the equipment under his control and by adopting and developing other means which he may conceive with a view to furthering this purpose. Whilst it is not given to us all to produce results of a far-reaching nature, the accumulation of effort and experience is a material aid to future development. To the extent to which the engineer is successful in these efforts, to that extent also will he be able to derive professional and personal satisfaction.

From the volume of technical data available relating to the development of steam power plant prior to and since the War, it is at once apparent that post-war development has been very rapid. It may therefore be claimed that the War and its consequent exigencies provided the urge, due to the fact that the factors contributing to the production of a unit of electrical energy increased so enormously in price at that period.

After the more stagnant period of the war years, rapid expansion and the fresh uses for electrical energy gave a renewed impetus to the supply industry, and the following remarks will briefly review post-war conditions in order to show that the turbine manufacturer has so perfected his plant that during the period under review the steam and heat consumption per unit generated has been approximately halved; also that the boiler manufacturer has so improved design and equipment that the operating engineer can utilize, at a very high efficiency, the lowest and cheapest grades of fuel obtainable. The result has been that the electricity supply engineer is able to sell his product at a price equal to, and in many cases less than, that obtaining before the War, and, at the same time, to keep pace with the increases in practically every item of his production costs.

TURBINE DEVELOPMENT.

The striking features of turbine development are: (*a*) The small rated capacity of the unit developed and in operation up to 1918, which did not exceed 10 000 kW at maximum output. (*b*) The maximum continuous rating of the modern turbo-alternator, which is now manufactured in units of 75 000 kW for use in this country, even larger machines being employed in the Continental and American power stations. (*c*) The greater reliability in the continuous operation of the combined machine which has been achieved during the past few years. (*d*) The development of alternators for generating current at a voltage of 33 000 volts. (*e*) The increase in the pressure and temperature of the steam employed for operating the turbine unit. (*f*) The development of large-capacity pass-out units, and their particular application in large industrial works in many parts of the world and in a number of important power stations. (*g*) The many improvements made to the auxiliary plant, which have enabled economies in steam consumption to be effected.

During the decade prior to the War, turbo-alternators of 6 000–10 000 kW capacity were practically standardized, and were considered to be large units. Throughout the same period no increases were made in steam pressures, 150–200 lb. per sq. in. being accepted as good practice. Final steam temperatures also varied little, from 350 to 500° F. The heat-drop available over this range of pressures and temperatures to a vacuum of 28 in. (which was regarded as good practice with the reciprocating type of air pump) was thus of the order of 300 to 320 B.Th.U. per lb. of steam, with a heat consumption of upwards of 20 000 B.Th.U. per kWh.

Turning to the period 1920–30 steam pressures have advanced from 250 lb. per sq. in. to 1 500 lb. per sq. in., and although, due to metallurgical limits, final temperatures have not risen so steeply, they have practically doubled, rising from 500° F. to 800° F. and, in certain instances, to 1 000° F. Again, the size and capacity of units have made remarkable strides. Machines with an output of 60 000–75 000 kW are under construction for operation in this country, and in America units of 160 000 kW capacity are being constructed by the Westinghouse Co. (U.S.A.). Whilst initial conditions have thus progressed, terminal conditions have not stood still. The full range of the heat-drop available can now be utilized to the best advantage.

The reciprocating type of air pump held the field for a long time, but as the size of units increased and pumps of much larger capacity were required this type was found to be costly and cumbersome, apart from its fixed capacity and its inability to deal with any abnormal circumstance. It has now been practically superseded by the steam jet for air extraction purposes. It is now not only possible but also common practice to maintain a terminal pressure consistent with the point where the gain in steam consumption is balanced by loss of heat in the condensate.

The combined influence of development in initial and terminal conditions has resulted in the available heat rising from 320 to over 500 B.Th.U. per lb. of steam.

Multi-stage feed-heating and reheating as means whereby an increase may be effected in overall efficiency are being resorted to in stations where conditions are favourable to such applications. From a thermodynamic point of view both are correct, and, of the two, feed-heating is the more favoured at the present stage of development, and it is now accepted practice. The additional plant involved represents but a small capital outlay, is simple in operation, has few complications, and serves the dual purpose of relieving the turbine of low-grade steam (which is of practically no loss to the machine) and of reducing the heat thrown away to the circulating water. Reheating, to warrant effectively the capital outlay on the additional plant necessary, must be carried out over a range of several hundred degrees, with the machine operating on a high load-factor. At the same time, it involves a number of restrictions in operation with which it is not always easy to comply, but the gains to be derived from its application—more particularly to a base-load station—will undoubtedly lead to a review of the problems involved, with a view to their simplification.

DIRECT GENERATION AT HIGH VOLTAGE.

Another development of far-reaching importance has been the construction and putting into commission of a 25 000-kW Parsons turbo-alternator to generate at 33 000 volts, in one of the leading London power stations. The machine has been in constant operation for over two years, and is, I believe, giving complete satisfaction. This contribution to post-war development is one of the outstanding engineering feats of modern times. The claims of direct financial savings in cables, transformers, cooling equipment, buildings and switchgear are stated to have been justified, and the breakdown hazard associated with such equipment on lower-voltage machines is eliminated. The fear that high magnetic leakage in the windings at this voltage would impair the efficiency of the machine and neutralize the savings effected, has proved unwarranted. Troubles on the distribution system to which the machine has been coupled, which have virtually amounted to short-circuits, have subjected the stator and end windings to severe stresses which have proved them to be quite as robust as those of a low-voltage machine. In view of the increase in the size of generator units the advent of this machine is important, inasmuch as, apart from the financial savings effected by the elimination of the items of equipment mentioned, it will considerably ease the increasing difficulty experienced in connection with lower-voltage machines of providing the necessary cable coupling between the stator terminals and the oil circuit-breaker.

As a result of rapid expansion, distribution lines have become longer and ever longer; economic circumstances have necessitated higher distribution voltages, and cable research has provided a satisfactory solution. Generator voltages have, however, remained constant, and the 33 000-volt machine provides another example of British engineering leading the way. Undoubtedly in future design, where a station is required to feed into a high-voltage network, machines operating at this or at an even higher voltage will be incorporated.

STEAM GENERATION.

Coincident with the progress in turbine design and operation a rapid development has taken place in steam generation, and in this direction the advance has been perhaps more striking. The tendencies on the boiler side are towards higher pressures and greater evaporative capacities. Linked up with the question of the capacity of boilers is that of the increased capacity of the firing equipment, whether in the form of mechanical stokers or of pulverized-fuel plant. These tendencies can be traced back to the advent on a commercial scale of pulverized-fuel firing, which has had a direct and very effective influence on the design both of mechanical stokers and of the boilers they are to operate.

Reviewing the trend of development, it is safe to say that the reliability of pulverized-fuel-fired boilers encouraged the tendency to increase capacity and reduce the number of units required for a given output of steam. Experience with furnace cooling, directed originally in the main at protecting the combustion-chamber structure, brought out very strongly the high comparative efficiency of radiant-heat absorption surface and pointed the way to increased average heat-transfer ratios throughout the unit. A judicious disposal of radiant surface therefore enabled improved evaporative capacities to be secured from boilers without the necessity of a proportionate increase in size. In other words, the generally-accepted principles of boiler design of a few years ago have been departed from, with the result that greatly increased steam outputs are now procurable from units the overall size and component parts of which are within the capacity of existing manufacturing and handling machinery.

This advance was initiated in the field of pulverized-fuel firing, and the success of the first large boilers inspired the necessary confidence to encourage a movement in the same direction in general boiler practice. So far as pulverized-fuel firing is concerned it was only necessary to establish the practicability of large boilers, following which the only limits to capacity were the estimated requirement of steam and the maximum sizes of drums, tubes, etc., procurable with present manufacturing equipment.

In regard to stoker firing, development on these lines has been hampered by the limitations of combustion equipment. The efforts are seen to have been immense when the improvements of the previous two decades are brought into comparison with present-day developments. Increased evaporative ratings have necessitated higher stoker ratings to confine grates within the dimensions of the boilers. To effect this it, has been essential to improve the whole principle of stoker design in regard to air supply and distribution, arch construction, and other factors influencing the rate of combustion. Similarly, much research into the form and construction of the surface of travelling-grate stokers has been necessary to produce an arrangement capable of standing up to the greatly increased wear and tear and the generally more arduous conditions it is called upon to withstand. The adoption of preheated air, either as a means of improving efficiency or as a necessity where feed-water heating is employed, while helping to increase stoker ratings has added to the difficulties of design owing to the reduced cooling effect on the grate surface. These obstacles have been contended with to a considerable degree, and already boilers of 250 000 lb. (per hour) evaporation are under construction for firing by travelling-grate stokers.

Although the maximum evaporative capacity now favoured is about 200 000 to 250 000 lb. per hour, there is no apparent reason why this figure should not be exceeded. The experience now becoming available will undoubtedly encourage further advances. Apart from the natural aversion to adopting any equipment of unorthodox design, the limiting factor at present is undoubtedly the combustion equipment—particularly so in the case of mechanical stokers. As regards pulverized-fuel firing, the corner firing system seems to be capable of adaptation to any practicable size of combustion chamber, and in conjunction with either duplicated unit mills or the storage system considerable further development may be expected. The technique of furnace design has so far advanced that boilers will in the future be able to operate continuously for much longer periods, and the need for stand-by units will diminish, making way for the increased capacities predicted.

The mechanical stoker, on the other hand, still needs considerable modification before boiler capacities much greater than those at present ruling can be contemplated, but there is no reason why the progress of the past few years should not be continued with this end in view.

In conjunction with increased capacities, the question of automatic control must be carefully considered. Already a number of reliable and effective automatic control systems have been applied to both pulverized-fuel-fired and stoker-fired boiler plants. Such arrangements are essential to the efficient operation of large boilers, and are readily applicable to them.

The quality of the boiler feed-water is now receiving much better attention than formerly, and there is no doubt that the importance of a pure feed-water supply will be fully realized and observed in practice in the future. Proper attention to feed water, coupled with the greatly increased service procurable from a well-designed and well-protected furnace, will enable boilers to be direct-coupled to turbo-generators to form single units operated throughout by a system of automatic control. An arrangement on these lines has already been installed in at least one prominent British power station, and there seems to be no reason why it should not become standard practice in capital power stations, with an enormous economy in floor space and capital cost of buildings housing the plant—due to the elimination of a separate boiler-room.

That this is by no means an over-optimistic prediction is evidenced by present tendencies. We already have boilers in England the evaporation of which approaches 300 000 lb. per hour. Against the average heat-transfer rates of 7 lb. per sq. ft. for water-tube boilers a few years ago, 10 lb. per sq. ft. is now a common figure, with ratings exceeding 40 lb. per sq. ft. in radiant-heat boilers. Furnace ratings of 25 000 to 30 000 B.Th.U. per cub. ft. are frequently met with, and these figures ought to be exceeded with improved methods of heat release. Stokers are now capable of burning up to 50 lb. of coal per sq. ft. of effective surface hourly, and an increase in the near future to 70 lb. or even more is not an unreasonable forecast. Progress in design is certain, and increase in boiler, furnace, and stoker ratings will all tend to make possible the larger evaporations aimed at. Boiler efficiencies have also shown a distinct upward trend, and the perfection of flue-gas heat-extraction equipment, combustion appliances, and insulating media will continue to reduce all but the uncontrollable losses until efficiencies exceeding 90 per cent, already secured with certain pulverized-fuel installations, will be procurable. Such efficiencies will have their effect in still further increasing the evaporation obtainable from a boiler of given dimensions.

TABLE.

Boiler Capacities of British Power Stations.

Owners and location of station	Working pressure	Type of firing	Number of boilers	Evaporative capacity per boiler
	lb. per sq. in.			lb. per hour
(1) London Power Co., Ltd., Battersea	600	Stoker	8	300 000
(2) County of London Electric Supply Co., Ltd., Barking ..	400	Stoker	8	275 000
(3) Synthetic Ammonia and Nitrates, Ltd., Stockton-on-Tees ..	800	Pulverized-fuel	8	270 000
(4) Birmingham Corporation, Hams Hall	375	Pulverized-fuel	5	228 000
(5) London Power Co., Ltd., Deptford	325	Stoker	4	200 000
(6) North Metropolitan Electric Power Supply Co., Ltd., Brimsdown	375	Pulverized-fuel	4	200 000
(7) County of London Electric Supply Co., Ltd., Barking ..	375	Pulverized-fuel	10	187 000
(8) Leeds Corporation, Kirkstall station	495	Pulverized-fuel	3	185 000
(9) Leicester Corporation	375	Pulverized-fuel	3	180 000
(10) Liverpool Corporation, Clarence Dock	450	Stoker	4	176 000
(11) Newcastle-upon-Tyne Electric Supply Co., Ltd., Dunston ..	625	Pulverized-fuel	2*	156 000
	625	Stoker	4*	156 000

* There are also four stoker-fired and two pulverized-fuel-fired reheating units capable of giving 125 000 lb. of steam per hour and reheating 200 000 lb. of low-pressure steam per hour.

It appears probable that the most serious obstacle to the development thus briefly sketched out will be the limitations imposed by existing machinery for the fabrication of boiler components. The use of jointless drums of solid forged construction as already adopted for high pressures will probably be extended, and there seems to be a good case for welded drums as an alternative to the riveted construction now usual.

Statistics of a number of typical installations operating in British power stations are given in the table, and these will serve to illustrate even more clearly the advance of modern times.

PERSONNEL.

The foregoing remarks will, no doubt, indicate the necessity for considering the personnel required for the efficient manipulation of the large combined units of the future. Whilst it is recognized that Associate Membership of the Institution is a qualification for any position on the technical side of a municipal undertaking, it is becoming more and more widely accepted that the importance of fuel characteristics and combustion problems will necessitate the engineering student including these subjects in his studies.

Consequent upon this, it would appear necessary that consideration should be given to the matter of effecting joint meetings between such institutions as devote their energies to the utilization of fuel, and our own Institution, to such an extent as will enable papers to be read and discussed by the members of both. In addition, the present members of power-station undertakings should be enabled to acquire full membership of fuel institutions on the presentation of a suitable thesis; or, alternatively, the Associate Membership class should at least be open to them, enabling them to qualify for full membership after they have obtained the requisite amount of experience and knowledge of fuel subjects.

With such knowledge at his command, the operator would be enabled to ensure the correct functioning of the automatic control of the whole of the combined equipment and thus obtain the maximum efficiency from the heat cycle. Such progress on the part of personnel would therefore be in keeping with the advanced knowledge which has mainly accrued during the past few years in plant development.

TEES-SIDE SUB-CENTRE: CHAIRMAN'S ADDRESS

By E. E. Dunn, Associate Member.

"SOME FACTORS AFFECTING THE USEFUL LIFE OF TRANSMISSION MAINS."

(*Address delivered at* Middlesbrough, 14*th October,* 1931.)

The tendency to utilize electricity for all manner of industrial and domestic purposes is becoming more and more general, and as this tendency approaches practical realization so will the electrical industry be saddled with a greatly increased responsibility for reliability of supply. Furthermore, as the value of any commercial commodity is ultimately measured in terms of cost, the sooner can we be certain of obtaining unfailing service from single, rather than duplicate, mains, the better will it be from the financial standpoint, especially when the wide areas through which transmission mains will have to be run to supply scattered villages and farms are taken into consideration.

With these thoughts in mind I propose in this address to refer to a few of the factors adversely affecting the useful life of various mains existing to-day. My remarks upon any specific weaknesses are based rather upon practical experience than upon theory.

I shall deal first with underground transmission, and then with overhead transmission. Any references to existing underground mains will be to paper-insulated, lead-covered and armoured cables laid direct, or to paper-insulated, lead-covered cables laid solid, all 3-core, fitted with plumbed lead sleeve joints, now working at pressures from 3 kV up to 20 kV, and varying in age from 5 to 25 years.

Underground Transmission.

Regarding the life of the chief materials used, it is of general interest to note that copper implements of warfare, lead water-pipes, porcelain vessels, and also, but more rarely, iron coats of armour, all centuries old, have at various times been found in a more or less good state of preservation. Mineral oils have apparently existed as oils for countless ages, whilst very old books, the paper of which could be deemed reasonably good, are still to be seen. All these materials appear to owe their long existence to two factors; (1) their natural resistance to deterioration and corrosive influences, and (2) the fact that they are at rest underground either directly or in vaults.

When these materials are made up in the form of a cable and put into commission underground, experience shows that by far the greater proportion of failures is due to physical movement in some form or other, and that the majority of these failures occur in, or near, joints, electrical breakdown being a result rather than a cause. This movement can be roughly divided under two headings, the first being expansion and contraction of cable cores when carrying current, and the second vibrational earth movement due to modern road traffic. The continued action of the former is liable to result in discontinuity or buckling of cores in joints. The second, in conjunction with the first, ultimately gives rise, particularly at joint sleeve ends, to crystallization and subsequent failure of lead sheaths. It is chiefly upon these aspects that my remarks will be based, as failures of experimental cables with much reduced thickness of insulating material, or those due to stray currents, electrolysis, acidulated earths, etc., are subjects of special study, while troubles attributable to faulty manufacture, accidental damage, or surge over-pressures are extremely rare.

Taking 50 deg. C. (the figure given by the Electrical Research Association as the maximum safe temperature-rise within an 11-kV cable) and a linear expansion of copper of 0·000017 in. per deg. C., every mile of core would, if entirely free, expand 4 ft. 5 in., whilst the lead sheath, with a linear expansion of 0·000028 in. per deg. C., would expand some fraction of this length per mile, depending upon the cooling of the surrounding medium.

The following abstract from a paper by Mr. J. Urmston entitled "The Electrical High-Pressure Testing of Cables and the Localization of Faults"* will further illustrate this. "For example, if a copper conductor 200 yds. long were raised 50 deg. C. in temperature, it would, if freely supported, increase in length by 6 in. If this movement were entirely restricted the copper would exert a force on the restraining body, amounting, in the case of a 3-core 0·3-sq. in. cable, to a total of 6 tons. The existence of these forces has been experimentally confirmed, etc."

Cables, when new, must obviously take up the major portion of this movement within themselves, but after a period of from 10 to 20 years has elapsed there is a tendency for the impregnating oil to solidify, accompanied by the formation of a paste-like substance commonly called "cheese." The outcome of this is a general stiffening-up of the insulating material, thus restricting the possibility of internal movement. The net result is that joints have to accommodate more and more of the longitudinal movement of cores.

On one or two cables of which I have knowledge, this stiffening or hardening of the insulating material is so pronounced that its removal very often necessitates the use of a hammer and hack-knife. (These cables are exceptional, I refer to them only for the purpose of showing what can take place.) Considering cables under normal conditions, as apart from joints, the above tendency is practically the only visible signs of deterioration, even in those over 25 years of age.

Many mains laid 20 to 25 years ago had their cores jointed by means of soldered one-piece or split ferrules, and the dissociation of cores from ferrules inside jointing sleeves has on many occasions resulted in electrical breakdown. Examination of such faulty joints has regularly disclosed either partial or complete disengagement between cores and ferrules, and in cases when these have been found correctly positioned a minute gap has at times been observed between the soldered cylindrical surfaces. In view of the consistency with which faults of this nature occur at times of light load, when cores draw, or tend to draw, apart, it would appear that alternate core tension and compression, consequent upon alternate periods of light and heavy loads, have an important bearing upon the occurrence of this form of trouble. Workmanship can be held responsible only to a very limited degree as many of these joints failed only after 10 and more years' service.

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* *Journal I.E.E.*, 1931, vol. 69, p. 685.

This particular class of failure is confined chiefly to mains of 0·1 sq. in. or over, and tends to become pronounced when the current density is permitted to be of the order of 1 500 to 2 000 amperes per square inch and where the load varies considerably at different periods of each 24 hours. It is also of general interest to note that such faults decrease in number during times like the present when industrial loads are much reduced.

On many systems ferrule jointing has been entirely replaced by copper-braided joints in general, or braided expansion-type joints in trunk mains. Although many of these have now been in commision from 15 to 20 years, so far as my experience goes no breakdown has occurred.

The other prominent source of weakness in underground mains is the lead sheath at its junction with the outer edge of the jointing sleeve plumbs. Many adverse features combine at these points, but the final cause of breakage is always movement of some kind, and, in particular, it is that resulting from road vibration due to modern road transport. This latter feature is liable to become pronounced on cables originally laid along highways, upon which, until the last few years, the passage of fast, heavy traffic was unknown.

Examination of many joints on cables laid under such conditions has shown sheath failures in various stages of progression. In some cases the sheath was crystallized and broken, and in others it was found to be thinning. On occasions, more generally associated with fully-loaded mains, approximately the first 6 to 12 inches of the sheath nearest the sleeves have shown peripheral ribs varying in pitch and height from $\frac{1}{2}$ in. downward. Initially, the nature of the lead appears to be altered and weakened by the localized heating needed when plumbing. Evidence for this statement is drawn from known cases of tension in subsidence areas, where sheaths are often found parted. The breaks always occur at the edges of plumbs. The natural motion of expansion and contraction is arrested here, whilst here, also, there is a change in the rate of heat dissipation.

Another factor (more particularly associated with low-lying moist lands, salt-bearing areas, and areas where mining is carried out at considerable depths) is a general slow settlement of the ground, the rate of which often varies at different parts of routes. For instance, I recently had to examine three joints on an 11-kV main, laid in about 1907, approximately 400 yards from a river. The cores in one of these joints were under tension, in the second they were normal, whilst at the third the lead sheath at one end had broken. In a more recent case, on a similarly laid 11-kV main, the cores, an hour after cutting, would not meet by $\frac{3}{8}$ in. Neither of these two cases was in a recognized subsidence area.

My remarks on this subject may be summarized in the statement that sheaths are weakest at that point where practice shows they should be strongest. The ideal solution, in my opinion, has yet to be achieved, but as a plumb need be little more than a watertight seal having slightly greater tensile strength than a sheath, any sleeve-end designs which bring the proportions of plumbs to a minimum, thus reducing the localized heating necessary, will be of assistance. An attempted method of eliminating possible failures here has been to "tin" the sheath for about 12 in. at the jointing ends. It is quite realized that this tinning may not form an alloy with the lead, but experience in subsidence areas has shown that a "tinned" sheath is not so readily parted as an untreated one. Another method, though not primarily intended for this purpose, is to "sweep down" the last two to four yards of the jointing ends, so that the joint is made below the general level of the cable and is thus further away from sources of vibration. Incidentally, the original purpose of this lowering of joints was to retard any tendency of fluid compounds to flow into the cable.

I do not propose to dwell upon the question of general failure of lead sheaths due to fatigue, etc., or upon the various tin, antimony or cadmium-lead alloys which have been evolved in attempts to overcome this trouble, as this subject has been discussed at length in the technical Press and is the outcome of special, rather than usual, circumstances.

Failures due to insulating tapes and compounds are rare, but failures have at times occurred at the junction of two insulating compounds. That is, flash-overs have taken place inside the cable, close to joints, across the junction of the cable-impregnating oil and the joint compound; flash-overs have also occurred across the contact surface where two different types of compound have been used, for special reasons, inside certain cable-terminating boxes. Along these surfaces, after a period of years, the insulating material sometimes degenerates into a substance which is little more than "mush." The question as to whether this deterioration is due solely to chemical action, or to differences in the electrostatic constants of the compounds, or to a combination of both, is rather controversial.

The chief reason for alluding to this particular topic arises from the thought that as there are hundreds of drum lengths of cable in service to-day which have been in successful commission for upwards of 20 years, and which show no prominent sign of senile decay, it would appear that the ideal method of joint insulation is to use, if not the same type of paper, then at least the same type of compound as is employed in the manufacture of the cable itself. The use of this compound, which is, of course, of a fluid or semi-fluid nature, would automatically prevent the formation of the spaces or voids that occur on cooling, in sleeves filled with so-called "hard" compounds.

With those of my hearers who may be inclined to remark upon the absence, in low-pressure distributors, of those weaknesses to which I have referred, I agree. The probable reasons are that the current loading of low-pressure distributors is limited largely by voltage-drop, whilst the maximum current density in transmission mains need be limited only by the permissible temperature-rise within the cable and the thermal resistivity of the insulation and surrounding earth. Also, the average low-pressure distributor often has the continuity of its close-fitting lead sheath removed at regular service joints, which, in contrast to only one joint per drum length in transmission mains, serve to accommodate core movement at frequent intervals *en route*. Further, the extent of any sheath movement at plumbs, due to expansion and contraction, is limited by the usual short distance between these joints, whilst low-pressure distributors are usually laid in footpaths where the rigidity of house foundations tends to reduce the amplitude of ground movements caused by traffic.

To summarize the foregoing remarks, I would suggest that the laying and jointing of high-pressure transmission mains necessitates consideration from a viewpoint entirely different from that applicable to low-pressure mains. Expansion and contraction are inevitable, whilst modern road traffic will gradually take its toll of lead sheaths, especially near joints. All the attention that can be bestowed upon these factors will be amply repaid in reliability, and we should be much nearer the ideal state of laying, and using to the fullest advantage, a main that necessitated little, if any, expenditure for maintenance during the whole of its lifetime, to which lifetime no definite limit has yet been assigned.

Before leaving the subject of transmission mains in the form of cables, terminal end-boxes warrant one or two observations with regard, chiefly, to pole-mounted boxes, as the liability of these to break down is much greater than with indoor types. The cause here, again, appears to be movement which originates from two main sources. One is atmospheric temperature variation causing unequal expansion and contraction of compound, castings and sheath; the other is that, unless precautions are taken, the sheaths of cables attached to end-boxes are subject to the decided disadvantage of being under tension from the beginning of their existence, cables, where they enter the earth, being very often placed in part of the land excavated to accommodate poles. In such circumstances, assuming a pole depth of 6 ft., and a ground settlement of 1 in. per foot, downward drag of the cable will certainly occur if it is laid soon after the pole has been erected. An examination of the supporting saddles of a cable so erected will often show it to have moved downward 2 to 3 in. Under these conditions, breakage of the sheath takes place at plumb edges in much the same manner as it occurs underground, but, as this feature has already been dealt with at length, reference will only be made here to its tendency to occur. Some idea of its prevalence may be gauged from the fact that of 49 large high-pressure boxes examined during 1930, 24 per cent had broken sheaths. The ages of the boxes varied from 6 to 20 years.

Failures due to the breakdown of compounds used as insulating materials are, as previously remarked, extremely rare, but, in the case of outdoor terminal boxes, failure to provide ample room for expansion has, on many occasions, proved a costly error. Forced joints, cracked lids, and displaced insulators, all providing access for moisture, with consequent electrical breakdown, have at various times been found. Happily, this feature is now being recognized by manufacturers, and the provision of expansion chambers is becoming much more general than hitherto.

A secondary feature, possibly not sufficiently recognized, is that the expansion and contraction of compound are accompanied by a form of breathing, and, unless special care is taken in the manufacture and final assembly of castings, a great danger exists of moisture being actually drawn inside the box, particularly where the separate castings are bolted together. The alternate tension and compression of voids which occur with the use of hard compounds, and which are so difficult to avoid in practice, have a tendency to aggravate this trouble.

OVERHEAD TRANSMISSION.

Passing now to overhead lines, limited, as before, to those designed for working at pressures between 3 kV and 20 kV, experience with these shows that it is not yet possible to produce the ideal state of constant unfailing service, systematic overhaul and renewal of parts being at the moment a necessary adjunct to their preservation and use. This remark is not intended to imply that modern overhead constructions are in any way fundamentally weak; in fact they are quite the reverse. The purpose of the statement is to suggest that in any considerations of first cost, which latter is, of course, much less than that for underground mains, it is essential that thought should be given to the attainment of maximum reliability, with minimum future maintenance, in order not to overburden an undertaking with heavy maintenance charges.

Considering an average line constructed with wood poles, copper conductors, porcelain insulators, and mild-steel supporting arms, insulator pins, stays, bolts and longitudinal earth wire, experience indicates that the probable order of ultimate failure of the chief material parts is as follows: Steelwork, poles, copper conductors, and porcelain insulators.

The problem of steel corrosion is one which has long exercised the minds of engineers, and we can only hope that the day is not so far distant when steel, impervious to corrosion, can be cheaply produced. The solution of the problem, so far as this branch of the industry is concerned, may yet be obtained by means of protective coatings, but experience has shown that to be of lasting service these coatings will need to have the qualities of copper or lead, and they will, for all practical purposes, have to form an integral part of the steel surface. Steel wires protected in this manner are on the market to-day. Rolled-steel sections, similarly protected, may provide the final solution. In the meantime, the position appears to be one of assisting the protective coatings in use, the most common form of which is galvanizing.

To erect galvanized steelwork without disturbing the continuity of the protective coating is wellnigh impossible. The galvanizing itself is liable to crack and flake, whilst the unavoidable rough treatment it receives during transport and laying out on site, the accidental hammering and the scoring by nuts, all have a tendency to expose the steel. This is then rapidly attacked, especially in industrial areas. In my opinion, formed as a result of experience in the overhaul of many lines, to paint all galvanized steelwork as erection proceeds, while the structures are new and clean, would greatly assist in lowering future routine overhaul charges. It is a costly proceeding to retard the formation of rust once it has begun.

Wood Poles.

In connection with wood poles, the chief cause of failure is dry rot. This usually commences about 2 ft. to 5 ft. from ground-level, the position where the greatest stress and liability to fracture occur. A particular feature of this decay is that its existence is rarely apparent externally. The outer 1 in. to 1½ in. is nearly always well preserved in poles which have been creosoted under pressure, but underneath this the timber becomes little more than powder, the amount of good core left being dependent upon its early discovery. The contributory causes appear to be the alternate moist and dry states occasioned by the weather gaining access to the uncreosoted wood through longitudinal cracks. These cracks develop during the slow pining which continually takes place, the younger and softer outside fibres shrinking more than those inside, and their formation is apparently accelerated by the stress to which the fibres near ground-level are subject. Only an inherently bad pole shows any sign of decay lower than about 1 ft. below ground-level.

"Sounding" of poles usually gives a good indication of the state of the timber. In suspected cases a sample, about ⅛ in. in diameter, bored and withdrawn by means of a special tool now on the market, ensures a more accurate knowledge. Wood poles have been known to remain sound for over 40 years, but dry rot in various stages has been found in poles considerably less than half this age. One form of effort to retard this trouble is systematically to fill any cracks which appear, by compounds with a tar basis, mixed with fine wood fibres. Painting by means of a compound of creosote and tar every three or four years also tends to fill up the finer cracks and replace any of the original impregnation which has been lost. It is just possible that dry rot may become more troublesome with poles erected since the War, due to the difficulties which have existed in obtaining thoroughly seasoned timber.

Copper Conductors.

Copper conductors have in the past occasioned no great anxiety so far as their use and durability are concerned, but recent tests have shown that a reduction in tensile strength takes place with age. Details of a series of tests giving evidence of this reduction were given in the discussion on a paper by Mr. P. J. Ryle on "Two Transmission Line Problems."* These tests show that the average tensile strengths per square inch of samples of 0·075 sq. in. stranded copper, continuously in use since 1912, are now only about 80 per cent of their original value, whilst those of samples of 0·1 sq. in. solid copper, four years older, are 92 per cent of their original value. This reduction is accompanied by increase of length, which, up to the present, has resulted only in the necessity for re-sagging after periods of use varying from 15 to 20 years.

The point of interest here lies in the application of the test-results to conductors of modern lines erected since the 1928 revision of the Electricity Commissioners' Regulations relative to overhead lines. Under these revised regulations the maximum stress in conductors is now permitted to be one-half of the breaking load, but the stress in the test conductors, when previously in use, was only one-fifth of the breaking load. In other words, the tension in modern conductors is now permitted to be 2½ times greater than that in conductors which, after 19 years' use, show a reduction of 20 per cent of their original strength. It would appear, therefore, that we may not be able to regard the conductors of modern lines, from the standpoints of useful life and safety, with the same comparative complacency as has been customary up to the present.

Before leaving this topic, some further reference should be made to the tensile tests mentioned. The interesting fact emerges that solid conductors show the effects of ageing to a much less degree than stranded conductors. Why this should be is a matter for investigation, but the results certainly open up the question as to which style of copper conductor will give the longer life.

Insulators.

The subject of porcelain insulators is one upon which little need be said with regard to durability. The permanence of good porcelain under normal conditions is generally accepted, whilst insulator design, so far as it concerns "pin" types, has been justified by results. Failures which do occur are, on the whole, due more to circumstances such as fouling by industrial pollution, stone-throwing, birds, etc.

The Effect of Lightning on Overhead Lines.

It may be fitting to conclude this address by a short reference to lightning as it affects overhead lines. These remarks are limited solely to observations and thoughts occasioned by experience, the purpose being to stimulate interest on the part of my hearers. For a scientific exposition of the subject, reference should be made to recent papers by Dr. G. C. Simpson* and Dr. H. Norinder.†

In connection with flash-overs on "live" transmission mains conforming in design to those under review, two features are rather outstanding. One is that the resultant damage is usually small, amounting in many cases to no more than a shattered or punctured insulator, and occasionally only to a streaking or discoloration of porcelain glaze. The other is that only occasionally do these flash-overs occur along the ordinary run of a line. In other words, the number of flash-overs which take place at positions where the electrical values of inductance and capacitance alter—such as at conductor make-off points, terminating ends, and at situations where transformers are connected—are much in excess of those which occur elsewhere. One cannot reasonably suppose that lightning directs itself specifically to these points. The more likely supposition appears to be that conductors are charged anywhere along their route, and that they do, in many cases, safely convey this charge up to positions where there is a pronounced change in their electrical constants. At these points the motion of the charge appears to be partially or entirely arrested, accompanied probably by a change in state of the energy from kinetic to potential, with subsequent release in the form of flash-over.

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* *Journal I.E.E.*, 1931, vol. 69, p. 805.

* *Journal I.E.E.*, 1929, vol. 67, p. 1269.

† *Ibid.*, 1930, vol. 68, p. 525.

From the information which is available it would appear that real damage on overhead lines in this country is limited practically entirely to live lines, and that rarely, if ever, do flash-overs take place on dead lines. Within the category of dead lines are those under construction in various stages of completion, and any established lines out of commission for long periods, regardless of whether these are earthed or not. That such dead lines receive charges is proved by the fact that linesmen have at various times received violent shocks while working on overhead conductors when unexpected thunderstorms have occurred, although the conductors in question were at the time connected to earth at each end.

Owing to the number of dead lines being always much less than those in commission, the likelihood of recorded flash-overs is less, but the possibility of them occurring, particularly at the same positions as on live lines, is suggested by a knowledge of the resistances of grounds through which conductors are sometimes connected to earth. These resistances may vary from 1 to 30 ohms, with occasional much higher values.

The effect of resistance is illustrated by the following extract from the Twentieth Kelvin Lecture, delivered by Dr. Simpson on " Lightning." The figure of current is the probable maximum instantaneous value in a lightning discharge. " As the conductor may have to dispose of a current of 100 000 amperes, every ohm of resistance gives a voltage of 100 000 volts on the conductor. Thus a local resistance or bad earth of 10 ohms will raise the potential of the conductor to 1 million volts, which will obviously tend to produce side discharges of a dangerous character, to say nothing of the heat developed at the fault."

Absence of visual evidence of flash-over on dead lines rather indicates that the energy of the average charges which occasion flash-over on live lines is comparatively small, and that the resultant damage is due more to the release of system energy than to that of the lightning discharge.

Of the various lines with which I am familiar, those not fitted with a longitudinal earth wire appear to be more susceptible to the effects of lightning than those on which an earth wire exists. Another feature connected with the subject is that the liability of lines to receive a charge is a function of their height above earth.

Consideration suggests three methods of procedure which, if used in conjunction, may be of benefit in diminishing the number of overhead feeder "outages" during electrical storms. The first is to erect a longitudinal wire, frequently earthed *en route*, directly below the conductors, in an attempt to reduce the amount of possible charge by decreasing the conductor height above earth—viewed from the electrostatic standpoint. Another method would be to erect a similar wire above the conductors to serve as an electrostatic screen. A notable example of this service of an earth wire, additional to its use as a fault-current return, occurs on the 132-kV grid lines. The second method is to endeavour to drain the energy of the charge to earth by means of non-inductive resistances, designed with special discharge-limiting characteristics; these devices to be fitted not only at the terminating ends, but also at regular intervals along the line. The possibility that some measure of success may be attained by this procedure is suggested by the apparently small energy of the average charge, which charge, when set in motion, appears to traverse quite long lengths of lines, eventually to result in damage, chiefly at specialized points. Alternatively, the purpose of a well-known surge absorber on the market to-day, built on the lines of a high-frequency transformer with short-circuited secondary, is to absorb part of the energy of a charge by means of induction and eddy currents.

A system of lightning protection somewhat akin to the idea of distributed drainage is at present the subject of experiment in America upon certain high-voltage lines. The *Electrical World* of the 4th October, 1930, published some details in connection with this.

An additional precaution suggested is to maintain the electrical constants of a line unaltered throughout, by so erecting conductors that no sharp angles or loops occur, and that their deviation from a straight line is no more than is necessitated by wayleaves, contour, or tensioning, in order to obtain the maximum attenuation of any charge from the whole of the line.

Finally, it should be noted that these observations apply solely to those discharges which appear to be seldom capable of doing great material damage. With lightning discharges of great magnitude, the dissipation of the energy of which results in wreckage, these remarks are in no way concerned.

Various investigators have, during the last few years, enormously advanced our knowledge of the nature of the more violent types of lightning discharges, and they may eventually evolve a complete solution of the problem so far as it concerns overhead lines. In the meantime, any procedure which is successful in preventing troubles arising from the discharges under review would do much toward promoting greater confidence in the use of overhead transmission lines.

HAMPSHIRE SUB-CENTRE: CHAIRMAN'S ADDRESS

By N. W. Prangnell, Member.

"OUR PROFESSION."

(*Address delivered at* Portsmouth, 14*th October*, 1931.)

The profession of electrical engineering comprises two sides, the theoretical and the practical. I think it might truly be said that 95 per cent of the problems the electrical engineer has to deal with are mechanical and 5 per cent theoretical. This indicates that the electrical engineer must be mechanically trained and inclined. The profession incorporates a very large number of individual trades. Those of us who are concerned with power stations or electrical manufacturing works are well aware of the number of particular trades and unions with which we have to deal. It is seldom realized by youths in their teens who think they would like to become electrical engineers, that they have to become proficient in a large number of specified trades and that if their training is not carefully supervised they may find themselves confined to one of these specified trades instead of being trained in the profession as a whole. In reviewing the electrical profession generally, one is impressed by the large number of men who have found their outlook and energies thus circumscribed.

Although necessarily of much more recent formation, our Institution has rapidly outdistanced in size the kindred institutions of mechanical and civil engineering. The memberships of the three Institutions are:—Civil Engineers, 10 599; Mechanical Engineers, 10 931; and Electrical Engineers, 14 548. This comparison indicates the importance of our profession and also brings home to us the fact that it is a profession of which we members should be very proud; we should do our utmost to maintain it at a high standard.

In my opinion the profession has not yet reached the status which it ought to have. An electrical engineer, and by that I mean one who is fully qualified and a member of the Institution, should be of the same standing as a doctor, solicitor, or architect, and should be readily accessible for advice in exactly the same way as are the members of these other professions. The reason why this Utopian state has not yet been reached is largely the fact that, as I have previously mentioned, a great many trades are incorporated in the profession and the electrical engineer has difficulty in becoming proficient in all of them. This has led to his being consulted as a specialist in his particular branch of the profession rather than as a general electrical engineer. As an illustration of this, I recently came across an instance in connection with the electrical equipment of a ship where one expert had been called in to deal with the generating plant, another to deal with the lighting and power installation and yet another to deal with the ventilation. Such a situation as this should not be possible.

To illustrate further that much remains to be done to raise the status of the electrical engineer, reference may be made to what occurs in connection with the erection of new buildings. An architect is at once consulted. He is given an absolutely free hand to draw up a specification, not only for the building itself but also for the lighting, heating, ventilation and lifts. This, in my opinion, is neither correct nor even business etiquette. The architect's work should be confined to the design of the building and decorations. Separate experts should be called in to prepare specifications for lighting, heating and ventilation. True, there are many cases where individual experts are employed, but the whole of the designing work for an exceedingly large number of the buildings which are erected is carried out by architects.

As far as electric lighting is concerned, the architect may confine himself to the position of the lights and then state that the work is to be carried out in accordance with the Regulations of the Institution, but who is to judge whether these Regulations have been fully carried out? Take our own district of Hampshire as an example. Building operations, large and small, are going on continually: a large number of wiring contractors are engaged in installation work, and the only expert supervision that the installations receive is that carried out by the electricity supply authorities. It is not the work of the staff of the supply authorities to examine electrical installations; in fact, in very few cases have they the power to inspect the electrical installations at all. Their responsibility ends in making sure that when the supply is connected to an installation it will not be likely to interfere with the supply to other consumers. As in every installation safety fuses are placed where the supply is connected, it is quite easy for the supply authorities to safeguard their networks against interference, however poor the installation may be.

In my opinion all electrical installations should be subject to inspection by a qualified electrical engineer. As regards the question of who would pay for such services, the responsibility rests with the insurance companies, who ought to satisfy themselves as to the safety and suitability of installations on which they are prepared to accept premiums for insurance. More respect for the electrical engineer would be obtained from the public by making it understood that the inspection of electrical installations is the work of a qualified expert.

For a number of years I have strongly advocated that no person should be employed on electrical work unless he has some qualifications, and that an unqualified person trading as an electrical engineer or calling himself such should be subject to heavy penalties. Anybody can call himself an "electrical engineer." We members of the Institution are entitled to certain letters, such as "M.I.E.E." or "A.M.I.E.E.," after our names. Further, since the time when the Institution was granted a Royal Charter we have been entitled to style ourselves "chartered electrical engineers," just as qualified accountants call themselves "chartered accountants." Since this designation was introduced I have never met a single instance where it has been used by a member of the Institution. The result is that the ordinary public does not know that the only qualified and registered electrical engineers are those who can call themselves "chartered electrical engineers." I think it is a pity that more advantage has not been taken of this designation with the view of lifting the status of our profession.

At various times it has been my duty as representing the Institution to report on firms trading as electrical engineers who have applied for registration as electrical contractors under the National Register of Electrical Installation Contractors, and my experience has been that less than 50 per cent of the applicants are qualified to call themselves "electrical engineers" or to carry out electrical work.

There is a large body of skilled workmen, who, although they have spent the whole of their lives in working on electrical installations and gear, cannot qualify for membership of the Institution. In view of this fact I have always contended that there should be a system of compulsory registration under the control of the Institution for all men who have the necessary indentures to show that they have served a proper apprenticeship, and are therefore practical workmen. Such a register would be rather larger than that controlled by the National Register of Electrical Installation Contractors, as this body only deals with the registration of firms who are qualified to carry out electrical installations, and does not cater for the employees of these firms or for men who may be carrying out practical electrical work in other firms or on their own account.

Since wireless became popular the number of so-called "electrical engineers" has grown tremendously. So long as the type of wireless apparatus employed was a self-contained unit in no way connected with lighting circuits, the importance from the point of view of safety of the apparatus being handled by a qualified man was not very vital. However, now that such a large percentage of wireless apparatus is directly connected with the lighting supply the position is very much altered, and a grave responsibility rests upon those who design and install such apparatus to ensure that users of wireless sets are not exposed to the danger of injurious electric shocks. Several cases have already occurred where fatal injuries have resulted from shocks obtained from wireless outfits. This again emphasizes the importance, from the point of view of the general public, of endeavouring to lift the profession of electrical engineering to a higher plane. It is a known fact that familiarity breeds contempt; the great use made of electricity for all purposes in these days, and the simplicity of the necessary apparatus, lead to the general idea that anybody can handle and install such apparatus. To raise a scare that electrical apparatus is dangerous would clearly be detrimental at this time, when electricity has become such an indispensable factor in everyday life. Therefore anything that can be done to improve the status of our profession and eliminate non-qualified workmen should be done by the method I have already suggested, namely registration, and also by giving publicity to the fact that only qualified and registered workmen should be employed.

I would again emphasize the fact that there are a large number of men engaged in electrical work who, although fully qualified by experience, are not members of the Institution and should therefore not call themselves electrical engineers. In my opinion this is unfair, and it should be possible to find a means by which these experienced men could be given the right to that title. I know of many men who are dealing with highly technical matters and the installation of intricate electrical machinery, who have not been able to pass the examination qualifying them to become members of the Institution, possibly because they are not proficient in some such subject as higher mathematics. I know of one man who has spent his whole life in the electrical industry, visiting power stations and consulting engineers, and discussing with them—on behalf of his firm—the most intricate electrical problems, and who is so far efficient that he has obtained many large contracts for his employers. It is also part of his work to supervise the carrying-out of contracts. This man has twice sat for the Institution examination without success. I think it will be agreed that such a man as this (and there are probably many) should be able to qualify himself in a practical way for the title of "electrical engineer," rather than by being forced to sit for an examination. In the early days of the Institution these qualifying examinations were not compulsory, and practically all the original members were admitted merely on the record of their experience and the personal knowledge of them vouched for by other members. I feel that the Institution should reconsider this subject, and I intend to direct my own efforts to this end.

Those of us who are in responsible positions are continually being asked for advice by parents whose sons are thinking of adopting electrical engineering as their walk in life. Personally I always start by saying that the boy should first of all be trained as a mechanical engineer, for the reason—given earlier in my address—that 95 per cent of an electrical engineer's work is mechanical engineering. Further, given the mechanical training, if the boy is keen on electrical work he will go to classes and study the theoretical side; thus when he has finished his apprenticeship he will really have a choice of two professions:—(*a*) mechanical engineering; (*b*) electrical engineering. In effect, an electrical engineer is a mechanical engineer who specializes in electrical matters. The alternative to the above is to place the boy at a technical institute, where in these days he will be trained almost as efficiently on the practical as on the theoretical side. I do not regard this as a good alternative because the practical workshops of the technical colleges do not carry out such a wide variety of work as is undertaken in a large manufacturing workshop.

I have a very high opinion of the "sandwich scheme" of electrical training, in which the students spend a certain amount of their time at a college and the remainder in various manufacturing works. Such a scheme as this, however, is expensive to parents, and naturally there are a large number who cannot take advantage of it.

In conclusion, I would summarize the subject matter of my address as follows. First, we are members of one of the finest professions that has ever been brought into being, and one of which we can all be very proud. Secondly, steps should be taken to raise our status so that the general public becomes as proud of us chartered electrical engineers as we are of our profession. Thirdly, steps should be taken to make it possible for men qualified by much experience to call themselves "electrical engineers" or possibly "registered electricians" as distinct from chartered electrical engineers, and such action should be taken as will educate the general public to the fact. If this is done it will be essential for Members and Associate Members of the Institution to describe themselves as "chartered electrical engineers."

SHEFFIELD SUB-CENTRE: CHAIRMAN'S ADDRESS

By I. Scott Mackenzie, Member.

"INDUSTRIAL POWER STATIONS AND THE GRID."

(*Address delivered at* Sheffield, *21st October,* 1931.)

After considering the subject most likely to interest the majority of an audience consisting of men who are engaged in so many and various branches of the profession of electrical engineering, I have decided that the question of "Industrial Power Stations and their Relation to the Grid" is probably a suitable one, and I hope that the brief address which I propose to deliver to you this evening will not only interest you but convince you of the absolute necessity of close co-operation between all parties who are concerned in making the national scheme a success and in producing the cheap and abundant supply of electricity of which we have heard so much and which we ourselves all look forward to receiving and rendering available to other people.

It is obvious that we, as an industry, cannot afford to face the possibility of a failure of the national scheme which is now being brought to fruition; and, this being so, it is, I submit, the duty of every member of our profession who is a good citizen to do everything in his power to help the national scheme.

A number of articles have appeared in the technical Press criticizing the grid, and pointing out that the possibility of a cheap and abundant supply of electricity is still remote and that the construction of the grid appears to be likely to raise rather than lower the cost of electricity to the consumer.

It has also been suggested that it is hopeless for the grid to contemplate competition with privately owned generating plant in a works where steam has to be raised not only for generating electricity but also for manufacturing purposes. However true these criticisms may be in certain special cases, they are, as a whole, purely destructive and therefore not likely to help the grid scheme in any way.

I hope to offer here some constructive suggestions which will help the scheme forward.

To begin with, let us consider the general objects of the grid, and then turn to discussing how far these objects have been attained. The Electricity Act of 1926 was drawn up primarily to supply the people of this country with cheap electricity so as to advance their social amenities and, at the same time, to assist them in manufacturing goods at a price which would enable them to meet competition with the markets of the world. The success or failure of this Act apparently depended upon three main factors:—

(1) The concentration on the generation of electricity at a comparatively few selected steam stations.
(2) The interlinking of such stations.
(3) The ability to obtain steam coal at a low price.

According to the figures published by the Electricity Commissioners for the year ending the 31st December, 1930, it would appear that they have received returns in respect of 559 generating stations which, I believe, are nearly all owned by municipal, railway and tramway authorities.

It would be very interesting if the Commissioners could see their way to publish a complete return of the non-statutory undertakings, viz. the generating stations in the large collieries and works of the country; I am sure that, if they did so, some most interesting and instructive information would be forthcoming.

Up to a point, in my opinion, the work which has been done by the Central Electricity Board and the Electricity Commissioners is excellent, particularly in the way of reducing the consumption of coal per unit generated. At the same time it must not be forgotten that the thermal efficiency even of the stations selected by the Commissioners, and, indeed, of super-stations in general, does not exceed 20 to 25 per cent. This, of course, is due mainly to the fact that the steam turbines in these stations use only the kinetic energy of the steam, and waste nearly all the heat content.

According to the latest returns, the amount of coal used annually in this country for all purposes is approximately 189 million tons. Of this amount about 35 million tons is used for domestic purposes; 118·5 million tons for manufacturing purposes; 18 million tons for the manufacture of gas; and about 10 million tons for the generation of electricity.

With the most up-to-date boiler plant it is claimed that an efficiency of 80 per cent is obtained from the coal and, assuming the calorific value of the coal to be 14 000 B.Th.U., 20 per cent, or 2 800 B.Th.U., is lost in the boiler, and 90 per cent of the remainder, or 10 080 B.Th.U., in the generating plant. That is to say, out of a total of 14 000 B.Th.U., 12 880 B.Th.U. are lost, and only 1 120 B.Th.U. are converted into electrical energy. In other words, for every 100 tons of coal used in this way the heat equivalent of 92 tons is lost; and, as the approximate total quantity of coal used in generating electricity in the United Kingdom is 10 million tons per annum, the huge total of 9 200 000 tons represents the approximate value (expressed in tons of coal) of wasted heat. This quantity, at an average price of even 20s. per ton (which is a very low figure to take), amounts to £9 200 000 out of a total of £10 000 000.

Since electricity is sold under statutory powers, the users have to pay the proportional cost of all this wasted heat, together with the cost of the electricity which is used up in driving numerous auxiliary plant, such as pumps for circulating water where cooling towers are used, and also fans which, in some cases, are used to blow away the heat from the cooling towers.

Assuming that the above figures are approximately correct, the question is: "Can anything be done to lessen the waste, or in what way can wasted heat be utilized?" The first main difficulty is to find a market for the heat; and, if this can be done, the further difficulty arises of co-ordinating the loads. Heat for warming houses, institutions and public buildings is required for only about six months of the year; and, with our climate, the heat load would vary very considerably. There is, however, a constant demand for hot water throughout the year, the quantity depending upon the type of buildings in any locality. The possibility of utilizing the heat depends very largely upon the position of the electric generating station in relation to that of other buildings requiring heat or hot water, on account of the difficulty and cost of transmitting heat to any great distance.

I cannot help feeling, therefore, that, from the thermal efficiency point of view, central stations should be of such a size and be so situated and designed as to meet the requirements of the immediate neighbourhood, whether for industrial or domestic purposes. The three essential services are power, heat and light, and it can be safely assumed that, in ten or more defined districts, not even two would require the same proportion of these services. The problem is admittedly a difficult one, but it is being seriously tackled on the Continent (particularly in Germany) and in America by the active co-operation of heating engineers with electrical engineers, and I feel that it would be in the national interests if something of the sort could be done in this country, particularly in densely populated districts.

For many years now at Staveley we have not only supplied electricity to the villages adjacent to our works and collieries, but have also made available a constant supply of really hot water at all hours in the houses. Exhaust steam is used to heat water in calorifiers for this purpose, the water being continuously circulated throughout a series circuit embracing the whole village. The householders, and particularly the women-folk, greatly appreciate their hot-water service, and gladly pay the small weekly charge which is added to their rent and which is just sufficient to make the scheme for each village self-supporting.

The first point I wish to make, therefore, is that, without in any way belittling the excellent work that has been done by the Central Electricity Board and the Electricity Commissioners, and whilst admitting that there may be a need for super-stations in certain areas, it is extremely doubtful whether, from a national point of view, and particularly when considering the conservation of our national coal (which is a wasting asset), it would not be better to keep alive and develop a large number of small stations on the lines mentioned above rather than close them down merely because in super-stations it is possible to generate electricity more cheaply, so far as the amount of coal per unit generated is concerned. In this connection it must not be forgotten that distribution and service amount to about 76 per cent of the cost of electricity to the consumer; transmission to approximately 14 per cent; and generation to only about 10 per cent of the total cost.

The immortal Faraday invented a machine which has been developed to an efficiency of about 99 per cent, and it seems incredible that a century should have elapsed without our being able to produce anything better than the present wasteful system of distribution. The stringent regulations now in force in connection with distribution and service mains should, in my opinion, be revised, and altogether cheaper methods of distributing and selling electricity brought into force. After all, the crux of the whole matter is the price the consumer has to pay for the electricity which he uses; and therefore, if, as I have said, distribution accounts for over 70 per cent of the total cost of electricity delivered to the consumer, it is obvious that this part of the business should receive the greatest possible attention and consideration. Without wishing to stress Continental practice unduly, I venture to say that, on the average, distribution is there carried out with very reasonable efficiency and far more cheaply than is the case in this country.

Assisted wiring schemes have already done much to render available supplies of electricity, even to the smallest houses; but nevertheless I feel that, up to now, only the fringe of the huge potential demand of the domestic load has been touched. In this country the supply of electricity is generally taken to be, more or less, synonymous with public electricity undertakings, and I have known several engineers associated with municipal central stations who were under the impression that private plants contributed but a negligible amount of the total electricity generated in the country. This is, of course, an entirely mistaken idea, as there are many privately owned industrial generating plants of size, importance and output comparable with those of leading municipal stations, while the methods used in such industrial generating stations are often of such economic value to the nation that extensions along these lines, where conditions admit, are in my opinion more to be desired than the erection of huge super-stations burning raw coal which may have to be transported at heavy cost over long distances.

Large quantities of low-grade fuels and also of exhaust steam are available at most collieries, with the result that it is generally found economical to generate electricity at the pithead for use not merely at the colliery itself but also for giving supplies to outside consumers in the neighbourhood.

Mr. J. A. B. Horsley, H.M. Chief Electrical Inspector of Mines, states,* amongst other things, that, out of a total of 1 725 546 h.p. of motors installed in the collieries in England, Scotland and Wales, no less than 1 093 380 h.p. (or 63·4 per cent) of the total supply of electricity comes from generating plant installed at the collieries.

Except in cases where large quantities of water have to be pumped, the average colliery load factor is not usually above 40 per cent, but when supplies of electricity can be given to outsiders in the neighbourhood the colliery generating plant can be run at a considerably improved load factor, and electricity can be sold cheaply and profitably during the evening lighting "peak" period, which generally coincides with the "valley" in the colliery station load curve.

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* *Journal I.E.E.*, 1931, vol. 69, p. 191.

The tendency towards privately owned works and colliery-power stations is very marked on the Continent, where single stations containing up to 70 000 kW are in existence. In the north of France nearly the whole of the power required is generated in large colliery stations in the Pas du Calais and the Nord coalfields, and private interests are in process of linking up these districts with the industrial regions of Lorraine so that, before very long, high-tension transmission lines will form a network covering almost the whole of France.

In the industrial districts around Liége, in Belgium, the same sort of scheme has been working for many years with excellent results, to the great benefit of the local industries, which are all—so to speak—partners in the production of a commodity in universal demand. Competition has given place to co-operation between industrial and municipal power stations and, since stations having load curves of widely different characteristics have been linked up and the whole system controlled from a central point, it has been possible to produce a cheap and abundant supply of electricity, and to run the plant in each station to the best possible advantage. Gas-engines, for example, run on blast-furnace or coke-oven gas, or a mixture of the two, are generally run continuously on full load and maximum efficiency, and fluctuations of load are dealt with by steam turbines. In other words, in France and Belgium at the present moment there are private interests which create a scheme similar to that of our national grid, but with waste-heat sources of power from collieries and works forming the basis of the supply.

I would suggest most earnestly that the Central Electricity Board and the Electricity Commissioners should give more serious consideration than they have apparently done as yet to our national basic industry of coal-mining, and allow colliery and works power stations to form a more important part of the grid system.

Turning now to the question of the improvement of load factor, which, in my opinion, above all else can really bring about a cheap and abundant supply of electricity and help the grid scheme to be a success, I would ask you to consider the domestic load and its potentialities. Until comparatively recent years, no really strenuous efforts seem to have been made to "push" the sale of electricity for domestic purposes, and this class of load has been left, more or less, to grow unaided. The result has been that, even in large cities, only a very small percentage of the total number of houses have been wired—even for lighting—and a very much smaller number for heating and cooking.

Last October at Manchester, Mr. A. L. Lunn, the Chairman of the North-Western Centre, in delivering his inaugural address, said that only 18·9 per cent of the houses in Manchester were equipped with electric wiring, and that a large proportion (66 per cent) of these were wired for lighting only. Mr. Lunn went on to say, and I can bear out his figures by my own experience in various parts of the country, that the following typical data for average domestic consumptions of electricity may be taken as being correct:—

	Units per annum
Lighting	200
Lighting and cooking	2 000
Lighting, heating and cooking ..	3 500
Lighting, cooking and water-heating ..	6 000
Lighting, cooking, water-heating and heating	7 500

It is obvious that unless heat can be sold direct from the power station in conjunction with the sale of electricity—as I have indicated earlier in my address—it is of enormous importance that the heating and cooking load (particularly the heating of water) should be developed, as this load occurs mainly during the off-peak hours of the average power station.

I have in my possession some figures which were given to me by a friend who lives in a large north-country city in an all-electric house, in which he consumes no less than 10 000 units per annum. The details of his account are as follows:—

	Units per annum
Lighting and small appliances ..	500
Cooking	2 000
Water-heating	5 000
Radiators	2 500
Total	10 000

His annual bill works out at 0·6d. per unit, and he is convinced that, even leaving health, cleanliness and all other such vital considerations on one side, he is saving money by using electricity for all purposes.

It seems to me that here again close co-operation is called for between all the interested parties, viz. the supply authorities, the cable manufacturers, and the firms who produce heating, cooking and other current-consuming apparatus—not to mention battery manufacturers, who can often make out a perfectly good case for the installation of a battery in large or medium-sized country houses on the outskirts of a supply area where the local supply authority is willing to sell electricity at specially low rates during restricted hours.

A great deal seems to depend upon consumers being able to get, easily and quickly, sound advice as to what to install in their houses, and to be able to count upon having their installations really well maintained at a reasonable cost.

Then the question of tariffs appears to call for co-ordination and simplification. In nearly every town in the country different tariffs are in operation, and I submit that, however sound they may be scientifically, the average householder is quite unable to understand them. As a result he is reluctant to equip his house with an installation which may cost him more to run than he can estimate. I am convinced, therefore, that every possible effort should be made to develop the domestic load, not merely by such official organizations as the Electrical Development Association but by supply authorities, interested manufacturers, and also by every individual electrical engineer, who should never lose an opportunity to preach the virtues of electricity, and, furthermore, put what he preaches into practice in his own house.

There can be no doubt, in my opinion, that the electrification of railways, and particularly the main lines, will play an enormously important part in making the grid a success. During the existing financial crisis it may be impossible to put such a scheme in hand, but I feel that it is bound to be undertaken before very long. Many suburban lines have already been electrified with excellent results, financially and otherwise, and I feel that, before long, we may hope that the main lines will follow suit. This would, of course, not merely greatly improve the load factor of the grid system but would also render supplies of electricity available in outlying districts far removed from towns and densely populated areas.

To sum up, therefore, I venture to make the following brief suggestions for consideration.

(1) Where conditions admit, every effort should be made to sell a large proportion, if not all, of the heat which is now wasted in most power stations; and, with this end in view, I submit that it would be better to develop rather than shut down the smaller power stations in densely populated industrial districts so that they may supply not merely electricity but also heat in the form of hot water.

(2) Works and colliery power stations should be linked up wherever possible with the selected power stations of the grid, so that the best use may be made of low-grade fuels and waste heat and steam, and also in order than an improvement of load factor may result from linking-up stations having load curves of different characteristics, so that the " peak " of one station may coincide with the " valley " in another.

(3) Every possible effort should be made to develop the domestic load, the potentialities of which are enormous.

(4) The electrification not only of suburban but also of main-line railway systems should be proceeded with as soon as economic and financial conditions permit.

(5) Last, but not least, the whole question, not merely of transmission, but of the distribution and sale of electricity, should be investigated and co-ordinated, and tariffs standardized and simplified.

FIELD TESTS ON THE "GRID" TRANSMISSION LINES.*

By J. S. Forrest, M.A., B.Sc.

(*Paper received 24th June, 1931.*)

Summary.

Part 1 of the paper deals briefly with the electrical constants of transmission lines, with special reference to steel-cored aluminium lines. Where possible, simple formulæ are given for the calculation of the various quantities associated with transmission lines, and the limitations of these formulæ are indicated.

In Part 2 an account is given of the methods which have been adopted for the determination of the constants of the "grid" lines. Three typical lines of diverse characteristics, viz. a 132-kV single-circuit line, a 132-kV double-circuit line, both transposed, and a 33-kV untransposed single-circuit line, are considered and results are given of measurements of 3-phase impedance, loop impedance, single-phase impedance, resistance, charging current, and induced electromagnetic and electrostatic voltages.

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Introduction.

The main object of this paper is to give an account of some measurements which have been made relating to the electrical constants of the "grid" transmission lines. While many of the tests performed and results obtained are commonplace and are included in the paper merely for the sake of completeness, it is hoped that some of the measurements will be found to be novel and not altogether devoid of interest. In addition, it is thought that the methods of measurement, which are very simple, will also be of interest to those engaged in the routine testing of transmission lines.

It is generally appreciated that in the operation of a system of transmission lines a knowledge of the constants of the lines is of great importance. The following are some examples of the uses of line constants. The resistance must be known in order to estimate the losses in transmission; the reactance, in addition to the resistance, is required in the calculation of the voltage-drop in the lines; and the reactance (or impedance) is also required in the estimation of short-circuit currents. Moreover, the single-phase impedance and the loop impedance must be known in order to determine the correct settings of certain types of protective gear, while the electrostatic capacitance is involved in the calculation of charging currents and voltage-rises in long lines and it also enters into questions relating to harmonics and system stability.

Part 1. Approximate Calculations.

It should be stated at the outset that steel-cored aluminium conductor is referred to throughout, as with the exception of the Brighton–Worthing and Northampton–Kettering sections all the "grid" lines are constructed of this type of conductor. Of course, the formulæ also apply—with more accuracy in some cases—to copper conductors.

As calculation usually precedes design and measurement, Part 1 of the paper will be devoted to formulæ for the evaluation of those quantities which are amenable to easy calculation. These formulæ are stated in the simplest form consistent with the accuracy usually required in practice, and although at first sight the assumptions made may not appear to be justifiable, it will be seen that they lead to fairly good agreement with the experimental results.

(*a*) *Equivalent Spacing of* 3-*Phase Line.*

If the distances between the conductors of a 3-phase line are D_1, D_2 and D_3 (Fig. 1), the equivalent spacing is

$$D = \sqrt[3]{(D_1 D_2 D_3)} \quad . \quad . \quad . \quad . \quad . \quad (1)$$

This quantity is of great use in calculations, as the inductance and capacitance of any transposed 3-phase line are equal to the corresponding quantities for a 3-phase line with conductors at the apices of an equilateral triangle whose sides are of length D; and the formulæ for this latter arrangement of conductors are very simple.

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* The Papers Committee invite written communications, for consideration with a view to publication, on papers published in the *Journal* without being read at a meeting. Communications (except those from abroad) should reach the Secretary of the Institution not later than one month after publication of the paper to which they relate.

(b) *Inductance of* 3-*Phase Line.*

The inductance to the neutral of a balanced 3-phase line is given in millihenrys per mile by

$$L = 0\cdot08 + 0\cdot741 \log_{10} (D/r) \quad . \quad . \quad . \quad (2)$$

where r is the radius of the conductor. D and r must be in the same units.

When only one frequency has to be considered it is often more convenient to calculate the corresponding reactance, which, at a frequency of 50, is given in ohms per mile by

$$X = \omega L = 0\cdot025 + 0\cdot233 \log_{10}(D/r) \quad . \quad (2a)$$

where $\omega = 2\pi f = 314$ at 50 cycles, f being the frequency.

For some purposes it is desirable to express the reactance of a line as a "percentage reactance" to a certain "base." In terms of the reactance in ohms the percentage reactance is

$$\frac{100\ IX}{E} = \frac{X}{10} \times \frac{\text{kVA}}{(\text{kV})^2} \quad . \quad . \quad . \quad . \quad (3)$$

where I is the base current in amperes, E the normal voltage to neutral, kVA the base kilovolt-amperes, and kV the normal kilovolts between phases. Two alternative forms are given because one is sometimes more convenient than the other.

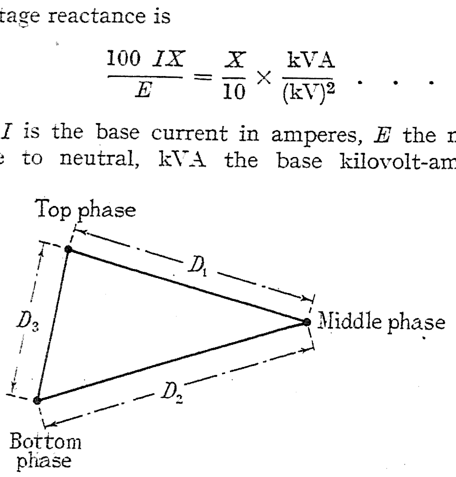

FIG. 1.—Spacing of a 3-phase line.

These formulæ hold strictly only for a homogeneous cylindrical conductor the current density throughout which is uniform, and it is therefore necessary to consider the magnitude of the effects which stranding, spiralling of the strands, and the steel core may have upon the inductance of the conductor.

Stranding a conductor reduces its inductance, but the spiralling of the aluminium strands magnetizes the steel core and so produces an increase in inductance. With conductors having only one layer of aluminium this latter effect is most pronounced, but if there are several aluminium layers—the lay of contiguous layers being reversed—the increase in inductance is negligible. Apart from the increase in inductance due to magnetization, the steel core produces a decrease in the internal inductance owing to its high resistance. To some extent it is possible to allow for these effects in the formulæ by using an equivalent radius for r, and by varying the constant term, but sufficient accuracy for practical purposes can usually be obtained by taking half the overall diameter for r and using the constant term given above for a homogeneous solid conductor.

In calculating the inductance of double-circuit line the effect of one circuit on the other may usually b neglected, the error introduced thereby being abou 2 per cent.

For untransposed lines formulæ (2) and (2a) give th average values of inductance and reactance for the three phases.

(c) *Resistance.*

The a.c. resistance R (ohms per mile) may be greate than the d.c. resistance, owing to skin effect and to the losses due to the magnetization of the steel core. Ski effect may be neglected for the conductors under con sideration, and the losses in the steel core become apparent only for conductors with a single layer o aluminium worked at high current densities (over 1 00 amperes per sq. in.), when the a.c. resistance ma exceed the d.c. resistance by about 10 per cent. I other cases, however, the a.c. and d.c. resistances ca be considered to be identical.

(d) *Capacitance of* 3-*Phase Line.*

The capacitance to neutral of a balanced 3-phase line is given in microfarads per mile by

$$C = \frac{0\cdot0388}{\log_{10}(D/r)} \quad . \quad . \quad . \quad . \quad . \quad (4$$

This formula ignores the presence of the earth and the effect of the earth conductor. The increase in capacitance due to the earth and the earth conductor is small (of the order of 1 or 2 per cent) and can be calculated for a given line if necessary.

The supporting insulators also increase the line capacitance to earth, but their effect is negligible. A reasonable value for the capacitance of a cap-and-pin type unit is $0\cdot00004\ \mu$F. If there are 9 units per insulator string and 6 strings per mile, as on the 132-kV lines, the increase in capacitance due to the insulators is only $0\cdot2$ per cent. For lower-voltage lines with fewer units per string and shorter spans the capacitance of the insulators is greater, but is still less than 1 per cent of the line capacitance.

Corona produces an increase in line capacitance as it forms a conducting envelope round the wire, but this effect is not of practical importance. In double-circuit lines the increase in capacitance due to the effect of one circuit on the other can usually be ignored. In the case of untransposed lines formula (4) gives the average capacitance to the neutral of the three phases.

Various useful quantities can be derived from the foregoing fundamental line constants.

(e) *Impedance of* 3-*Phase Line.*

The 3-phase impedance to the neutral of a balanced 3-phase line is given numerically (in ohms per mile) by

$$Z = \sqrt{(R^2 + X^2)} \quad . \quad . \quad . \quad . \quad (5)$$

Z is also termed the "balanced impedance" or the "symmetrical impedance," and it is the impedance to positive or negative phase-sequence currents.

(*f*) *Charging Current.*

The charging current (in amperes per mile) of an electrically short line is given numerically by

$$I_c = \omega C E_s \quad . \quad . \quad . \quad . \quad . \quad (6)$$

where E_s is the line voltage to neutral and C is expressed in farads per mile.

(*g*) *Voltage-Drop.*

The impedance-drop in a line is given in vector volts * by

$$\boldsymbol{E}_s - \boldsymbol{E}_r = \boldsymbol{I}\boldsymbol{Z}l \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (7)$$

$$= \boldsymbol{I}(R + jX)l \quad . \quad . \quad . \quad . \quad (7a)$$

where $\boldsymbol{E}_s$ and $\boldsymbol{E}_r$ are the voltages to the neutral at the sending and receiving ends, $\boldsymbol{I}$ is the line current, and l the length of line in miles.

By taking the modulus of (7*a*), or by projecting on the real and imaginary axes of the vector diagram (Fig. 2), equation (7*a*) becomes

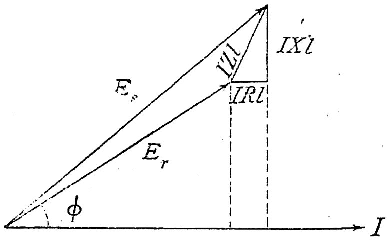

FIG. 2.—Vector diagram for short line.

$$E_s^2 = (E_r \cos\phi + IRl)^2 + (E_r \sin\phi \pm IXl)^2 \quad . \quad (8)$$

where cos ϕ is the power factor at the receiving end.

Formulæ (6) and (7) for charging current and voltage-drop only apply approximately, the rigorous formulæ being

$$\boldsymbol{I}_c = (\boldsymbol{E}_r/\boldsymbol{Z}_0) \sinh \boldsymbol{A}l \text{ (vector amperes)} \quad . \quad . \quad (9)$$

and

$$\boldsymbol{E}_s = \boldsymbol{E}_r \cosh \boldsymbol{A}l + \boldsymbol{I}_r\boldsymbol{Z}_0 \sinh \boldsymbol{A}l \text{ (vector volts)} \quad . \quad (10)$$

where $\boldsymbol{A} = \sqrt{(\boldsymbol{Y}\boldsymbol{Z})}$

$\boldsymbol{Z}_0 = \sqrt{(\boldsymbol{Z}/\boldsymbol{Y})}$ (the characteristic impedance),

and $\boldsymbol{Y} = j\omega C$ (the vector admittance, for zero conductance).

The approximate formulæ (6) and (7) are derived from (9) and (10) by retaining only the first term in the expansions of the hyperbolic functions, but the errors introduced by this approximation become appreciable only for lines more than 50 miles long.

(*h*) *Length of Catenary.*

Line constants are expressed in terms of the length of the conductor catenary, although it is usually the length of the line route (i.e. the sum of the span distances) that is known. No allowance need be made, however, for the difference between " conductor miles " and " route miles." For example, in a 132-kV line at 15° C. having a span of 900 ft. and a sag of 18 ft. the difference between the length of the conductor and the span length is only 0·11 per cent.

Part 2. MEASUREMENTS.

Part 2 deals with measurements made on the " grid " lines, and the line constants obtained experimentally may be compared with those calculated (where possible) by the methods outlined in Part 1.

(*a*) *Value of Measurements.*

It may be asked why it is necessary to make any measurements in view of the fact that the most important data required can easily be obtained by calculation. It must be remembered, however, that measurements were necessary in order to justify some of the simplifying assumptions made in the calculations, and that new practical conditions may arise which do not lend themselves to easy computation. Moreover, resistance measurements indicate the presence of a faulty joint in a newly erected line, or the overall deterioration of the conductor in an old line. In addition, want of balance in a transmission line can be detected by the measurement of impedance or of induced electromagnetic voltages.

In view of the above it seems that the usual " pressure test " of a line is inadequate and that, in addition, a series of quantitative tests such as are now about to be described should always be carried out.

(*b*) *Types of Lines Tested and Quantities Measured.*

Table 1 gives particulars of the three lines from which the results quoted in subsequent sections were obtained. As far as their electrical constants are concerned these lines are typical examples of " grid " lines, or, for that matter, of any modern high-tension transmission lines. Although these three lines appear very different to the eye, they differ little in their electrical constants.

Measurements were made, although not on all the lines, of:—(i) Three-phase impedance, (ii) single-phase impedance, (iii) loop impedance, (iv) resistance, (v) charging current, (vi) induced electromagnetic voltages, and (vii) induced electrostatic voltages.

(*c*) *Method of Testing.*

All the quantities mentioned in the previous section, with the possible exception of induced electrostatic voltages, can be measured with the help of a low-tension 3-phase supply and the usual measuring instruments. The use of a low-tension testing supply has many advantages. No elaborate precautions need be taken to ensure the safety of the persons carrying out the tests, while it is a simple matter to make the connections to the instruments and to provide satisfactory insulation where necessary. Moreover, since the line voltages and currents usually come within the range of the instruments, potential and current transformers need not be employed. In the present tests the substation auxiliary supplies—3-phase, 50-cycle, 400 volts between phases—were used.

The method of making connections to the lines may be of interest. The 132-kV lines are led down directly

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* Vector quantities are indicated throughout the paper by bold-faced type, thus $\boldsymbol{Z}$.

TABLE 1.

Line	Voltage	Single circuit or double circuit	Length	Transposed or Untransposed	Line conductor	Overall diameter of line conductor	Earth conductor	Spacing D_1	Spacing D_2	Spacing D_3	$\sqrt[3]{(D_1D_2D_3)}$
Bonnybridge–Abernethy	kV 132	Single circuit	miles 47·1	Transposed	30/0·11 in. diam. aluminium 7/0·11 in. diam. steel 0·175 sq. in. copper equivalent	in. 0·77	12/0·11 in. diam. aluminium 7/0·11 in. diam. steel	ft. 20·8	ft. 23·7	ft. 12·4	ft. 18·3
Abernethy–Dundee	132	Double circuit	20·6	Transposed	30/0·11 in. diam. aluminium 7/0·11 in. diam. steel 0·175 sq. in. copper equivalent	0·77	12/0·11 in. diam. aluminium 7/0·11 in. diam. steel	24·1	12·4	13·1	15·7
Leatherhead–Dorking	33	Single circuit	4·5	Untransposed	6/0·186 in. diam. aluminium 7/0·062 in. diam. steel 0·1 sq. in. copper equivalent	0·558	6/0·186 in. diam. aluminium 7/0·062 in. diam. steel 0·1 sq. in. copper equivalent	12·6	13·5	7·6	10·9

to the substation, and satisfactory connections can be made by bolting leads to the appropriate isolators. Earthing poles which clip on to the substation busbars are sometimes useful in making connections to the lines, but they should be employed only when there is already a high resistance (such as a voltmeter) in circuit, as they may introduce a contact resistance of the order of 1 ohm. The 33-kV lines are usually cabled as they approach the substations, and about a mile of cable may be employed. This cable is useful as a surge-absorber and in alleviating wayleave troubles, but it is slightly inconvenient from the point of view of line measurements. As the capacitance of the cable is about 20 times, and the reactance about half, that of the equivalent line, it is necessary to make the instrument connections at the terminal tower of the line.

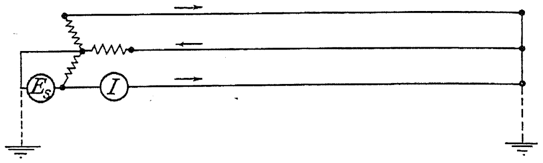

FIG. 3.—Measurement of 3-phase impedance.

If care is taken in the arrangement of the sequence of tests it is possible to obtain measurements of many quantities with comparatively few alterations of connections at the receiving end of the line.

(*d*) *Measurement of 3-Phase Impedance.*

If E_r is equated to zero, equation (8) becomes

$$E_s = I\sqrt{(R^2 + X^2)}l = IZl$$

so that the 3-phase impedance (in ohms) is the ratio

$$\frac{\text{Sending-end voltage to neutral } (E_s)}{\text{Line current in amperes } (I)}$$

when the line is short-circuited at the receiving end (Fig. 3). It is immaterial whether or not the line is earthed at the receiving end, but it is often convenient to use the earthing switch to short-circuit the line. If the transformer neutral is also earthed, a path is formed in which zero phase-sequence current may flow, but no trouble has been experienced from this cause.

TABLE 2.

Line	Three-phase impedance, in ohms per mile	
	Measured	Calculated from formulæ (3) and (5), using values of resistance given in Table 4
Bonnybridge–Abernethy	0·72	0·71
Abernethy–Dundee	0·70 per circuit	0·69
Leatherhead–Dorking	Top phase 0·69 Middle phase 0·75 Bottom phase 0·73	—

In a properly transposed line it should not be possible to detect any difference between the impedances of the three phases. In untransposed lines with scalene triangular spacing the impedance of the phases may differ by about 10 per cent, and it is usually easy to see, by considering the flux linkages, which phase is likely to have the highest impedance and which the lowest. This is illustrated in the case of the Leatherhead–Dorking line (Table 2).

(*e*) *Measurement of Single-Phase Impedance.*

By single-phase impedance is meant the impedance of one phase and earth return. It is this impedance that is involved in the determination of line-to-earth fault currents, and it is therefore of importance in connection with protective gear and inductive interference with communication circuits. All the lines under consideration have high-conductivity earth-wires bonded to earthed steel towers, so that the impedance of the return circuit is much reduced owing to the earth conductor and towers providing alternative return paths.

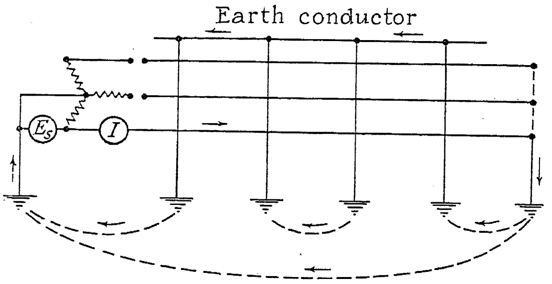

FIG. 4.—Measurement of single-phase impedance.

The connections for the measurement of single-phase impedance are given in Fig. 4. The phase in question is earthed at the receiving end, and one side of the single-phase supply must also, of course, be earthed. If it happens to be more convenient, all the phases may be earthed at the receiving end as this will not affect the results. The single-phase impedance (in ohms) is the ratio

$$\frac{\text{Sending-end voltage to earth } (E_s)}{\text{Line current in amperes } (I)}$$

and within the limits of experimental error it should be the same for each phase of a properly transposed line. In untransposed lines a variation of the order of 5 per cent may be expected in the single-phase impedances of the three phases, the impedance being greater for phases farther from the earth conductor.

If the power loss in the circuit is also measured a value can be obtained for the resistance of the earth and earth-conductor return path. As the power factor is about 0·3 a wattmeter which reads correctly at low power factors should be used for this purpose.

In a double-circuit line all phases of one of the circuits may be earthed at both ends and a measurement of single-phase impedance made on one of the phases of the other circuit, thus providing four high-conductivity earth wires. This is a condition which might easily arise in practice if one circuit was out of commission. It will be noticed, however (Table 3), that the single-phase impedance is only reduced by about 10 per cent under these circumstances. The single-phase impedance of a transmission line with a high-conductivity earth-wire cannot be calculated by means of a simple formula.

TABLE 3.

Line	Single-phase impedance, in ohms per mile
Bonnybridge–Abernethy	1·05 (Resistance of return path = 0·16 ohm per mile) (Power factor = 0·33)
Abernethy–Dundee	1·04 (One circuit completely isolated) 0·94 (One circuit earthed at both ends)
Leatherhead–Dorking	Top phase 0·97 Middle phase 0·99 Bottom phase 1·01

(*f*) *Measurement of Loop Impedance.*

Although a knowledge of the loop impedance is not nearly so important as a knowledge of the single-phase impedance, the former is of some interest in connection with phase-to-phase faults. The loop impedance in ohms is the ratio

$$\frac{\text{Voltage across loop formed from two phases } (E)}{\text{Amperes in loop } (I)}$$

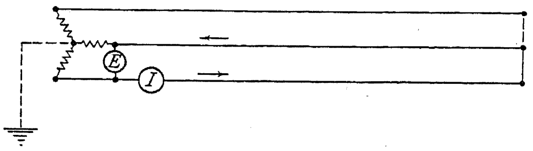

FIG. 5.—Measurement of loop impedance.

In the measurement of loop impedance (Fig. 5) it is convenient to short-circuit all three phases at the receiving end and measure in turn the impedances of each of the three possible loops. The receiving end of the loop must not be earthed if the neutral of the supply is earthed.

As in the previous cases, no difference should be detected between the impedances of the three loops of a transposed line. As shown in Table 4, in an untransposed line loops of greater area have greater impedances.

TABLE 4.

Line	Loop impedance, in ohms per mile of loop
Abernethy–Dundee	1·35
Leatherhead–Dorking	Top-middle loop 1·46 Middle-bottom loop 1·47 Bottom-top loop 1·38

(*g*) *Measurement of Resistance.*

If a line is short-circuited at the receiving end, the d.c. resistances of each of the three pairs of phase con ductors may be measured; a bridge megger or an ordinary Wheatstone bridge is a suitable instrument for this purpose. Alternatively, or in addition, the a.c. resistance can be obtained by measuring the watts dissipated during the measurement of 3-phase impedance or of loop impedance. This method is less accurate than the first-mentioned, as it involves the square of the current and is also subject to the errors sometimes associated with wattmeter measurements at low power factors, but it must be employed when the true a.c. resistance is required. Any difference found between the resistances of the three phases should be within the limits of experimental error. The air temperature should be taken when resistance measurements are being made, as it at least serves to give some idea of the temperature over the entire length of the line.

TABLE 5.

Line	Resistance, in ohms per mile		Temperature
	D.C. method	Wattmeter method	
			°C.
Bonnybridge–Abernethy	0·235	0·232	5
Abernethy–Dundee	0·227	—	1
Leatherhead–Dorking	0·438	—	18

The values of resistance obtained on three "grid" lines are given in Table 5. The resistance and 3-phase impedance being known, the 3-phase reactance can be found. For example, using the figures given in Tables 2 and 5, the inductive reactance of the Bonnybridge–Abernethy line is found to be 0·68 ohm per mile, or, expressed as a percentage reactance at 100 000 kVA by means of formula (3), 0·40 per cent per mile.

TABLE 6.

Line	Measured charging current	Capacitance, deduced from (6)	Capacitance, calculated from (4)
	amperes per mile	μF per mile	μF per mile
Bonnybridge–Abernethy	0·33 at 132 kV	0·0139	0·0141
Abernethy–Dundee	0·375 at 132 kV	0·0158	0·0144
Leatherhead–Dorking	Top phase 0·0934 Middle phase 0·0890 Bottom phase 0·0926 at 33 kV	—	—

(h) Measurement of Charging Current.

If the line is open-circuited at the receiving end and energized from a 3-phase supply (Fig. 6), the charging current (at 400 volts between phases) can be measured with a moving-iron a.c. milliammeter provided the line in question is of moderate length, say 20 miles. For short lines it is necessary to use a milliammeter of the thermal type.

In transposed lines the charging current should be the same for all phases, while in untransposed lines it is in general different for each phase, its magnitude depending upon the position of the phase and earth conductors.

Some measured values of charging current, converted to normal line-voltage, are given in Table 6. The increase in capacitance of the double-circuit line due to the proximity of the two circuits is apparent, one of the circuits being earthed.

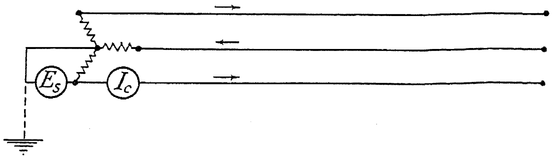

FIG. 6.—Measurement of charging current.

(j) Measurement of Electromagnetic Induced Voltage.

By electromagnetic induced voltage is meant the voltage induced in a circuit by the alternating magnetic field from a neighbouring circuit. The induced voltage is proportional to the current in the inducing circuit and to the length of "parallel."

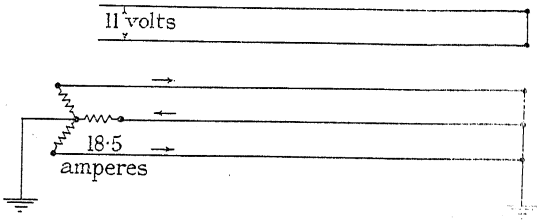

FIG. 7.—Electromagnetic induced voltage.

Although not of much practical importance, the following measurement of electromagnetic induced voltage is of interest. The voltage in a loop formed by two phases of one circuit of the Abernethy–Dundee line was measured while balanced 3-phase currents were flowing in the other circuit (Fig. 7). The voltage induced in a loop by a transposed 3-phase line carrying balanced currents should be zero if the loop has the same position with respect to the line conductors throughout the length of the line. In the present case the loop consisted of two phases of a 3-phase transposed circuit, so that a small induced voltage might have been expected. The measured induced voltage was 11 volts when the inducing current was 18·5 amperes. The measured induced voltage was probably partly due to imperfect transposition and to zero phase-sequence currents.

(*k*) *Measurement of Electrostatic Induced Voltage.*

The so-called electrostatic induced voltage in a circuit is due to the alternating electric field from a neighbouring circuit. The electrostatic induced voltage is proportional to the voltage of the inducing circuit and is, within limits, independent of the length of "parallel." Two measurements of electrostatic induced voltage will be mentioned.

(i) One phase of the Bonnybridge–Abernethy line was charged from the a.c. supply to a potential of 410 volts with respect to earth, the line being open at the receiving end. The voltage to earth induced in one of the free phases was measured with a multicellular electrostatic voltmeter and was found to be about 60 volts.

TABLE 7.

Inducing voltage, between phases	Induced voltage, phase to earth
kV	kV
90	0·75
97·5	0·90
100	0·95
118	1·10
120	1·13
132	1·25*
142	1·35

* Induced voltage, measured between phases = 2·15 kV (Note that 2·15/1·25 =1·72).

(ii) Both circuits of the Abernethy–Dundee line were opened at the receiving end and the voltage induced in one circuit was measured while the other was charged to about 132 kV between phases. The induced voltage was measured with a Kelvin 3-plate electrostatic voltmeter. The results obtained are given in Table 7; the fact that the graph (Fig. 8) is a straight line passing approximately through the origin illustrates the direct proportionality between inducing and induced voltages.

(*k*) *Measurement of Resistance of Wet Fishing Line.*

In conclusion, a test of a rather different character from the foregoing is perhaps worthy of mention. It was thought that there might be a possibility of danger to a fisherman who allowed his fishing line to come into contact with a high-voltage transmission line at a river crossing. Accordingly, a piece of flax line (size 1) was soaked in water from the rivers in question (Hampshire Avon, and Test) and its resistance was measured. Flax line was used as it was likely to have a lower resistance than any other type of line. The resistance of the wet line was found to be about 0·5 megohm per cm length of line; thus a fisherman would be unlikely to receive a serious shock, even from a 132-kV line (76 kV to earth), if a few yards of line were interposed between him and the live conductor. The most interesting feature about the test was the fact that the resistance of the wet line could be temporarily reduced to about one-quarter of the above value by running it through the fingers, presumably owing to the effect of secretions from the skin.

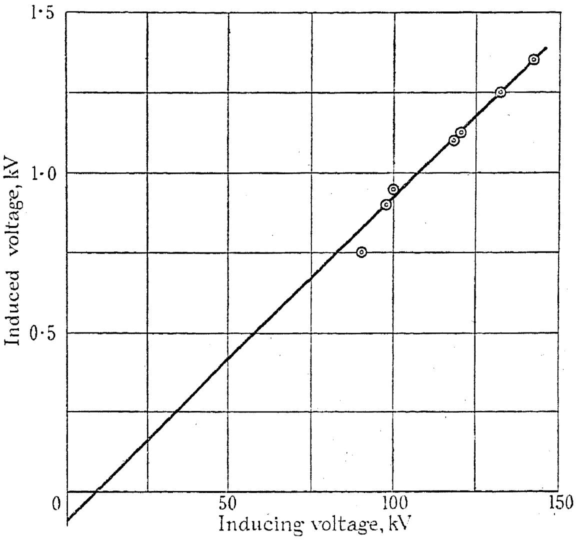

FIG. 8.—Electrostatic induced voltage.

Finally, although it is impossible to make adequate acknowledgments, the author wishes to express his gratitude to all who were concerned in the tests.

DISCUSSION ON

"AN ELECTRICAL METHOD FOR DETERMINING THE MOMENT OF INERTIA OF A DIRECT-CURRENT ARMATURE."*

Prof. D. Robertson (*communicated*): The determination of the moment of inertia of a d.c. armature can be carried out by a much simpler electrical method than the one described in the paper. All that is necessary is to run the machine as an unloaded motor for a sufficient time to get the bearings into a steady state, to measure the power absorbed by the armature when running steadily with the same field current at each of two neighbouring speeds about equally distant from that used during the preliminary run, and then to observe the time taken to fall from one of these speeds to the other when the armature current is cut off but the field current is maintained constant. The stroboscopic vibrator is by far the best speed-indicator for running-down tests, for it gives a sharp indication, by the reversal of the motion of the pattern, of the instant when certain speeds are passed. Naturally, stationary speeds on adjacent patterns would be chosen for the two speeds. Full experimental details will be found in a paper† published in the *Journal* in 1915, but as that paper was concerned with the analysis of the losses it did not give the calculation of the moment of inertia, which was not needed. It may be given here. From the test data quoted on page 320 (vol. 53) of that paper we get:—

Net power taken by armature when running steadily:—

At 1 250 r.p.m. = 391 W
At 1 154 r.p.m. = 350 W
Mean (1 202 r.p.m.) = 371 W
Difference of speeds = 96 r.p.m.

Time taken to fall from 1 250 to 1 154 r.p.m. with field on = 2·26 secs.

Hence

Mean torque during retardation

$$= \frac{371 \text{ watts}}{1\,202 \text{ r.p.m.}} \times \frac{1 \text{ rev.}}{2\pi \text{ radians}} \times \frac{60 \text{ secs.}}{1 \text{ min.}}$$

= 2·95 joules per radian

Mean deceleration

$$= \frac{96 \text{ r.p.m.}}{2{\cdot}26 \text{ secs.}} \times \frac{2\pi \text{ radians}}{1 \text{ rev.}} \times \frac{1 \text{ min.}}{60 \text{ secs.}}$$

= 4·45 radians per sec. per sec.

Moment of inertia

= 2·95 (joules per radian) ÷ 4·45 (radians per sec.^{2})
= 0·662 kg-m^2
= 2 270 lb.-(in.)^2

The mass of the armature was 245 lb.; hence its radius of gyration was 3·04 in. Its diameter was 10 in.

Dr. J. C. Prescott (*in reply*): Prof. Robertson's remarks introduce the consideration as to how far accurate experimental results can be obtained from substitution in an approximate formula. Stated symbolically, the formula used by Prof. Robertson is

$$\text{Moment of inertia} = \mathbf{I}' = t\left[\frac{P_1 + P_2}{\omega_1^2 - \omega_2^2}\right]$$

where P_1 is the watt loss due to iron, friction, and windage at angular velocity ω_1; P_2 the watt loss at angular velocity ω_2; and t the time taken for the machine to decelerate from ω_1 to ω_2, without external supply of power to the armature, under the conditions of excitation corresponding to the losses P_1 and P_2. In this formula the definite assumption is made that the time-interval t is so small that the relations between P and ω and between ω and t are sensibly linear throughout the interval. If, following the general assumption, the loss may be represented by

$$P = k\omega^2 + k'\omega \text{ watts}$$

where k and k' are constants, then the relation between angular velocity and time for a machine decelerating from an angular velocity ω_0 is given by

$$\omega = \epsilon^{-kt/\mathbf{I}}\left(\omega_0 + \frac{k'}{k}\right) - \frac{k'}{k} \text{ radians per sec.}$$

and the moment of inertia ($\mathbf{I}'$) calculated from Prof. Robertson's formula can be shown to bear to the true moment of inertia ($\mathbf{I}$) the relation

$$\mathbf{I}' = \mathbf{I}\left[1 + \frac{k^2t^2}{\mathbf{I}^2}\left(\frac{1}{3} + \frac{k'}{4k\omega}\right)\right]^*$$

if $kt/\mathbf{I}$ is small compared with unity, where ω is the average angular velocity over the interval t.

For the machine to which reference is made in Prof. Robertson's paper: $k = 0{\cdot}0144$, $k' = 1{\cdot}125$, $t = 2{\cdot}26$. Taking $\mathbf{I}$ as 0·662 and ω as 126·0, the error term is found to be 0·115 per cent, which is certainly not exceptionable. The value of the moment of inertia derived from Prof. Robertson's formula, however, depends directly for its accuracy on the correct assessment of the time-interval t, and an accuracy of 1 per cent in the calculated value of $\mathbf{I}'$ presupposes a similar accuracy in the measurement of t, i.e. t must be measured to within 0·02 sec. in the case cited, which would be difficult of accomplishment without some special form of apparatus such as a stroboscope and a good chronometer. Even so, the average error shown by the readings published in the paper is 2 per cent. It is here, therefore, rather than in the assumptions of the formula, that the important approximation occurs when t is small. If the time-interval be extended to 16·5 secs., the moment of inertia calculated from Prof. Robertson's formula is 0·695, which, taking 0·662 as the true value of the moment, gives an error of 5 per cent. Admittedly, if the availability of a stroboscope and chronometer be presupposed, his method of determination has decided advantages over the "quantity meter" method (the most important is, I think, that the angular velocity is measured directly and not derived from a measurement of voltage), and is certainly of simpler technique. The method described in my paper, however, only requires for its application instruments of general occurrence and can be used to give results having a mean error of 0·5 per cent. The performance of the test may be simplified by the use of a small instrument which has just come on to the market, which combines the functions of a stop-watch and a revolution counter.

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* Paper by Dr. J. C. Prescott (see vol. 69, p. 1179).

† D. Robertson: "Separation of the No-Load Stray Losses in a Continuous-Current Machine by Stroboscopic Running-Down Methods," *Journal I.E.E.*, 1915, vol. 53, p. 308.

* I am indebted to Mr. U. S. Haslam-Jones, M.A., for the statement of this equation.

DISCUSSION ON

"THE CIRCLE DIAGRAM OF THE POLYPHASE INDUCTION MOTOR."*

Mr. H. M. Clarke (*communicated*): While the equivalent circuit (Fig. 1 of Mr. Hawkins's paper) including r_1 appears to be nearer actual conditions than when r_1 is omitted, the resultant circuit fails to represent the conditions when the machine is supplied via the rotor.

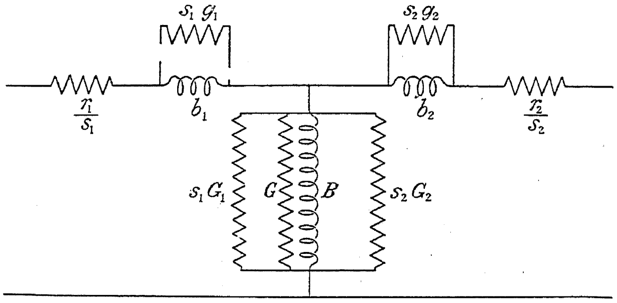

FIG. A.

It is desirable that the equivalent circuit should represent the motor, whether it is short-circuited at the R_2/s_2 end and supplied at the R_1/s_1 end, or short-circuited at the R_1/s_1 end and supplied at the R_2/s_2 end, where s_1 and s_2 are the slips at each end. This symmetry is restored if r_2' is moved so that it occupies the same position on the right as r_1 does on the left. Unfortunately it is unlikely that r_2' could thus represent correctly the iron loss in the rotor. The addition of a third resistance r_3' across R_2'/s_2 to the full circuit of Fig. 1 might meet the case, and it certainly brings back the reversibility feature. The following circuit is, however, more consistent: add to Fig. 1 two resistances shunting X_{L1} and X_{L2}' respectively, placing r_1 in parallel with r_2'. These additional resistances represent the core loss not provided for by r_1 and r_2'. If there is justification for separating X_{L1} and X_{L_2}' from X_{Mg} and from each other, there is justification for allowing them their own losses, since each may have its associated secondary in masses of metal (iron or copper) forming closed circuits and dissipating energy. Moreover, in so far as r_1 and r_2' may be assumed constant, the resistances shunting X_{L1} and X_{L2}' may also be taken as constant. If any closer representation of facts is required than is given by the usual circuit (Fig. 1, omitting r_1) it should take the form shown in Fig. A. In this figure the symbols have been simplified, and the distinction between primary and secondary has been omitted to preserve symmetry and reversibility. s_1 becomes unity if power is supplied on the left, s_2 unity when power is supplied on the right. Consideration of which is stator and which rotor is avoided by assuming unity as the ratio of transformation. Leakages are shown as susceptances for greater convenience in converting to Fig. B. While it is not opportune to show the derivation of the *sg* and *sG* terms, it should be noted that just as r_2/s_2 does not represent copper loss but must be divided into r_2 and $r_2[(1/s) - 1]$ (the former representing copper loss, the latter power for torque production) so $s_2 g_2$ must be divided into $s_2^2 g_2$

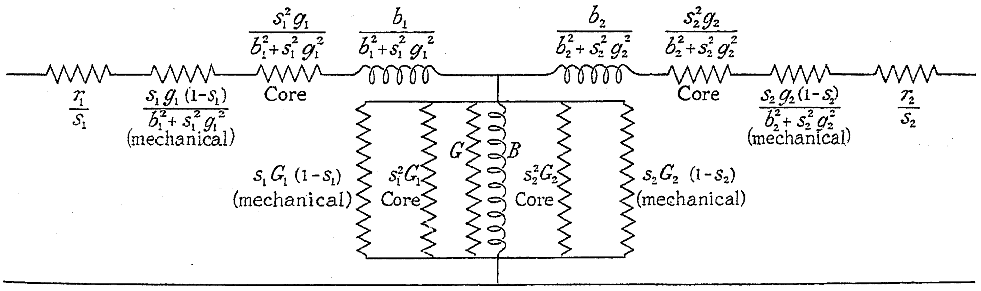
$\frac{r_1}{s_1}$
$\frac{s_1 g_1 (1-s_1)}{b_1^2 + s_1^2 g_1^2}$
(mechanical)
$\frac{s_1^2 g_1}{b_1^2+s_1^2 g_1^2}$
Core
$\frac{b_1}{b_1^2+s_1^2 g_1^2}$
$\frac{b_2}{b_2^2+s_2^2 g_2^2}$
$\frac{s_2^2 g_2}{b_2^2+s_2^2 g_2^2}$
Core
$\frac{s_2 g_2 (1-s_2)}{b_2^2 + s_2^2 g_2^2}$
(mechanical)
$\frac{r_2}{s_2}$
$s_1 G_1 (1-s_1)$
(mechanical)
$s_1^2 G_1$
Core
G
B
$s_2^2 G_2$
Core
$s_2 G_2 (1-s_2)$
(mechanical)

FIG. B.

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* Paper by Mr. C. C. HAWKINS (see vol. 69, p. 1149).

and $s_2g_2(1 - s_2)$, and sG_2 into $s_2^2G_2$ and $s_2G_2(1 - s_2)$. $s_2^2g_2$ and $s_2^2G_2$ thus represent the core losses in the rotor associated with the leakage flux and the common flux respectively, leaving $s_2g_2(1 - s_2)$ and $s_2G_2(1 - s_2)$ available for torque production. Experiment shows that a constant conductance G across B is necessary to indicate iron loss unaffected by rotation whether the motor is supplied via the stator or rotor. For calculation or derivation from test data, the components of s_1g_1 and s_2g_2 can be converted to series equivalents, and the final circuit takes the form shown in Fig. B. It has several interesting features, e.g. iron loss changing from common field to leakage fields as slip increases, iron loss positive whether slip is positive or negative. I am working on this subject at the moment, and hope shortly to have experimental confirmation of this circuit.

Mr. C. C. Hawkins (*in reply*): The equivalent circuit proposed by Mr. Clarke is of interest as covering the case of the induction motor with rotor used as primary, with which my paper does not deal. As to whether the data required for its use can be successfully calculated during the process of design, there may well be some measure of doubt; it is to be hoped that light may be thrown on this point as the result of further experiment and experience.

DISCUSSION ON "LOSSES IN D.C. MACHINES FROM NO-LOAD TESTS." *

Dr. E. Hughes (*communicated*): I am very gratified to find that the author's experimental work confirms the method suggested by myself for calculating the iron loss in d.c. machines when loaded, especially as I had not the opportunity of checking it by actual load tests. My figures† were based on results obtained with no armature loading, but with the main field distorted by means of a compensating winding. The author's formula for the "test factor" (page 1304) looks rather formidable at first, but almost the whole of it can be worked out once and for all for a given machine and the remainder can be deduced from the magnetization curve, so that in practice the formula is comparatively easy to apply. It is not clear how the author has applied the method suggested by F. W. Carter‡. In the latter's original paper the armature ampere-turns acting at the pole-tip were taken as $IZ\psi/(4qp)$, using the present author's symbols. No reason was given in that paper as to why the value of these ampere-turns was taken as half the true value, except that the method gave results which agreed closely with tests made under load conditions. The fact that in the present paper the iron loss calculated by Carter's method is about half-way between the uncorrected no-load loss and the true loss, suggests that the author has faithfully followed Carter's method and taken the distorting ampere-turns at the pole-tip to be those deduced from the above expression. If so, I should like to inquire whether the use of the correct distorting ampere-turns would give an iron loss in reasonable agreement with the true value.

Mr. R. G. Isaacs (*in reply*): In applying the method suggested by F. W. Carter the excitation was increased by an amount corresponding to half the distorting ampere-turns. If the full value of the distorting ampere-turns had been used the losses in all the tests given in the paper would have come out too high, the amount depending on the degree of distortion. In Tests Nos. 7 and 8, for example, the respective losses would have been 8 and 12 per cent too high, while in Test No. 4 the losses in the motor are 7 per cent too high even when the distorting ampere-turns are taken at half their true value.

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* Paper by Mr. R. G. Isaacs (see vol. 69, p. 1303).

† *Journal I.E.E.*, 1925, vol. 63, p. 35.

‡ *Ibid.*, 1927, vol. 65, p. 994.

PROCEEDINGS OF THE INSTITUTION.

819TH ORDINARY MEETING, 22ND OCTOBER, 1931.

Mr. Clifford C. Paterson, O.B.E., Past-President, took the chair at 6 p.m.

The minutes of the Annual General Meeting and of the Extra Ordinary Meeting held on the 14th May, 1931, were taken as read and were confirmed and signed.

A list of candidates for election and transfer, approved by the Council for ballot, was taken as read and was ordered to be suspended in the Hall.

The Chairman announced that 706 donations and subscriptions to the Benevolent Fund, amounting to £414, had been received during the period April to September.

The Premiums (see vol. 69, pages 802 and 1043) awarded for papers during the past session were presented by the chairman to such of the recipients as were present.

Mr. Paterson then vacated the chair, which was taken by **Mr. J. M. Donaldson, M.C.,** President, amid applause.

Col. Sir Thomas F. Purves: It is my pleasant duty to propose a resolution expressing the thanks of the Institution to the retiring President; a resolution which will, I am sure, meet with the ready acceptance of this audience. Mr. Paterson has conducted himself with unfailing dignity and distinction throughout a year that has made an exceptionally heavy demand upon his office as our principal representative. He opened the session with a presidential address of remarkable interest and charm. He has been a tower of strength in the Council and on our many committees, and he has also distributed quite a large amount of ripe and well-distilled wisdom, in support of worthy causes, on the many occasions on which he has had to speak for the Institution. We all admire the grit with which he stood up to his duties in spite of the severe and most unfortunate attack of sciatica from which he suffered during the early part of his presidency, just at the time when he had to move about so much among the Local Centres. We are glad to think that that trouble is now a thing of the past, and we sincerely hope that it may remain so. We are very appreciative also of his conduct of the heavy duties of these later days, when he has had to combine the presidency of the International Illumination Congress, and the direction of our own Summer Meeting, with a very full and active part in the Faraday Centenary Celebrations. Mr. Paterson has given ungrudgingly and unsparingly of his best in the interests of the Institution throughout the past year, just as he has done in previous years and as we know he will do in the years to come. I feel it an honour to have to propose this resolution, which reads: "That the best thanks of the Institution be accorded to Mr. Clifford Paterson for the very able manner in which he has filled the office of President during the past year."

Mr. B. Welbourn: I should like to endorse to the full all that Sir Thomas Purves has said about the most successful year that we have had with Mr. Paterson as our President. Those who have been present at meetings of the Institution or who have sat under him at the Council table have seen the very efficient way in which he has conducted our proceedings and the added dignity which the Institution has gathered during his presidency. Mr. Paterson has been very unsparing in his services to the Institution. He has not only presided over all the meetings of the Council and the Institution in London, but has also been quite unsparing in his services to the Local Centres. I was glad to see that in an address to one of the latter he laid great stress on the importance of physics and chemistry to the younger men in the profession. He himself is an outstanding example of the importance of the connection between physics and electrical engineering. I should like to refer to the unfortunate accident which Mr. and Mrs. Paterson met with during the summer, and to congratulate them both upon their entire recovery from the effects of it. I have much pleasure in seconding the resolution proposed by Sir Thomas Purves, and I am quite sure that, although Mr. Paterson has now retired from office, he will continue for a long time to come his keen interest in our affairs.

The resolution was then put to the meeting by the President, and was carried with acclamation.

Mr. Clifford C. Paterson: I appreciate more than I can say the very kind remarks of Sir Thomas Purves and Mr. Welbourn and the overwhelming way in which they have been received. This has indeed been a wonderful year, and I shall always feel grateful that I was elected to hold the presidential office in it. If I have been able to merit but a tithe of the approbation which you have so kindly expressed I ought to feel indeed gratified, for it is an inspiring experience to be allowed to serve the Institution, and, through the Institution, the profession of electrical engineering. The office of President is, however, made very easy for its occupant by the capable and self-effacing staff of the Institution, inspired by the guidance and example of the Secretary. This is no formal acknowledgment of the services of Mr. Rowell and his staff. If the present year has been a heavy one for the President, it has been doubly heavy for the staff of the Institution, and yet there has been no increase in its numbers and no falling-off in the high level of efficiency of its work and organization. I want to take this opportunity of thanking Mr. Rowell and all the members of the staff of the Institution for their work during the very arduous year through which we have passed. I feel that you would also wish me to remember another band of workers who have earned our unstinted praise—Colonel Vignoles and his staff of workers at the Faraday Centenary Exhibition. This Exhibition will redound to the credit of the Institution so long as this generation lasts. During the present year the electrical engineer has been brought face to face with the origins of his art and has come to see that that which gave him life a century ago is still his life-blood now. Whatever this or future years may have in store, 1931 will always be remembered by its message that scientific study is the traditional and the true atmosphere which all electrical engineers must breathe if their outlook is to remain healthy and productive.

The President: I have a duty to perform in regard to one of our Honorary Members, Thomas Alva Edison, who passed away a few days ago in his 85th year. He was elected an Honorary Member of the Institution in 1927. Edison was undoubtedly a very great inventor, and although some enthusiastic compatriots of his have over-emphasized the part he played in regard to certain inventions, I do not for a moment suppose that Edison himself was any party to that sort of thing; he was so wrapped up in his work that such questions did not concern him greatly. I have said he was a man of many inventions. According to a recent article in *The Times*, his output during his later years was one patent every 11 days—a truly astonishing performance. Some of his inventions were undoubtedly of world-wide importance. I suppose the earliest and one of the best known was the gramophone. Perhaps the most important invention or discovery made by Edison was that of the incandescent electric lamp, which made possible electric lighting as we now know it. A wrong attitude in regard to that invention has been taken up on the other side of the Atlantic, because Swan, one of our Past-Presidents, actually produced lamps before Edison did. It was a singular thing that these two men, separated as they were by 3 000 miles, should almost at the same time have produced practically the same article by different methods. I think we may call it the "Ediswan" lamp, as indeed it used to be called in this country. Edison had no sooner found it possible to get small units of light than he became exceedingly busy in making dynamos, which he constructed in a very rule-of-thumb manner; in fact, he used to say that when they designed a machine in the early days they were never sure whether it was going to generate 50 or 200 volts, the figure they were aiming at being 125. It took the genius of one of our Past-Presidents, Dr. John Hopkinson, to work out systematically the whole magnetic theory of the subject, the result being the highly successful Edison-Hopkinson dynamo. American technical literature contains constant references to the "Edison system." The Edison system consists partly in the use of three wires (the well-known 3-wire system) and partly in a very curious and strong mechanical construction which Edison used in the early days for his distributing mains. It was made up of three stout rods placed in an iron pipe which was filled up with pitch. Some of these distributing mains are in use to this day. Whether or not Edison invented the 3-wire system I do not know, but Dr. Hopkinson went one better by inventing a 5-wire system, which operated very successfully in Manchester for a considerable number of years. Later Edison invented a very successful alkaline secondary battery, which is still being sold and used to-day. As soon as the news of Mr. Edison's death reached the Institution a telegram of sympathy was sent to his relatives in America, and I think that in view of his very great attainments you would like to indicate your sympathy with his family by standing for a moment, which I now ask you to do.

The members then stood in silence for a few moments.

The President then delivered his Inaugural Address (see page 1).

Mr. Ll. B. Atkinson: I have to propose "That the best thanks of the Institution be accorded to Mr. J. M. Donaldson for his interesting and instructive Presidential Address, and that with his permission the Address be printed in the *Journal* of the Institution." The Institution is fortunate in regard to its presidential addresses, because it is able to draw from so many of the ever-widening circle of different interests included in electrical engineering. We have presidential addresses which are almost purely scientific; we have also presidential addresses such as the one we have heard to-night, in which the general public, if they could have heard it, would have been almost as interested as we ourselves have been. Mr. Donaldson is very modest about his own capabilities. Recently, in the course of some correspondence which I had with him in connection with certain inventions, he wrote that he himself had never made an invention and that he did not believe he ever would. That is perhaps a matter for congratulation, for some of us who have been associated with inventions have derived more anxiety than profit from them. Mr. Donaldson has told us a little about the early days of electricity supply companies. I was one of the founders of the Kelvinside Electric Co., and was also associated with the initiation of the Westminster Electric Supply Corporation, which was started to carry out a contract for supplying the House of Commons with electricity from a plant in Millwall, where one of the first Parsons turbo-generators was used. As the President has mentioned, in those days we had to choose a favourable opportunity for laying our mains, and although we might have no powers to cross a street, nobody had any powers to make us remove our cables once they were installed. We had wayleaves all down Victoria-street, and by getting a big gang of workmen together one night we laid the mains along the whole of the street before the morning. In that way we started the Westminster Co. To return to my duty, Mr. Donaldson has given us a very interesting résumé of the history of the electricity supply industry and I have much pleasure in moving the above resolution.

Mr. J. M. Kennedy: I have much pleasure in seconding this resolution. The President has given us a great deal of interesting information and food for thought, and it is well that those of us who are engaged in launching new methods of electricity supply should be reminded of the difficulties encountered by the pioneers.

The vote of thanks was then carried with acclamation.

After the President had briefly replied the meeting terminated at 7.50 p.m.

INSTITUTION NOTES.

Members from Overseas.

The Secretary will be obliged if members coming home from overseas will inform him of their addresses in this country, even if they do not desire a change of address recorded in the Institution register.

The object of this request is to enable the Secretary to advise such members of the various meetings, etc., of the Institution and its Local Centres, and, when occasion arises, to put them into touch with other members.

Faraday Centenary Publications.

A limited number of surplus copies of the following publications, which were on sale at the recent Faraday Centenary Exhibition, are available and can be obtained from the Secretary of the Institution at the prices indicated:—

Faraday Centenary Exhibition Souvenir Catalogue and Guide, one shilling, post free.

London (a story of the City in a form different from that given in the conventional guide book), two shillings and sixpence, post free.

Postcards.—These are in sets of 12, price 1s. per set, post free. Three of the illustrations have been reproduced in the *Journal* (No. 419, November, 1931), and the others depict:—

Faraday and Mrs. Faraday—from a daguerreotype.
Portrait of Faraday with bar of his heavy glass.
Faraday in the Lecture Theatre of the Royal Institution. Christmas Juvenile Lectures on Metals, 1855-56. The Prince Consort in the Chair.
Faraday at work in the old laboratory at the Royal Institution. From a contemporary water colour.
Very early galvanometer made and used by Faraday.
Faraday's "great" electromagnet.
Faraday's specific inductive capacity apparatus.
Title page from Faraday's bound notes of Sir Humphry Davy's course of lectures on Chemistry. It was this volume which Faraday sent to Davy and which led to his engagement as scientific assistant in the laboratory of the Royal Institution. Bound by Faraday himself.
Front of the Royal Institution, Albemarle Street, London, W.1.

Faraday Centenary Celebrations Overseas.

The Centenary of Faraday's discovery of electromagnetic induction was celebrated at Sydney, New South Wales, on the 22nd September, the celebration taking the form of a conversazione at the University of Sydney, at which commemorative addresses were delivered, under the chairmanship of Mr. L. J. Reynolds, B.E., by Prof. J. P. V. Madsen, D.Sc., B.E., on "The Life and Work of Michael Faraday, and Applications of his Discovery of Electromagnetic Induction," and by Prof. O. U. Vonwiller, B.Sc., on "The Influence of Michael Faraday's Work on Modern Science." The local members of the following bodies co-operated in the celebration:

The Institution of Electrical Engineers.
The Institution of Civil Engineers.
The Institution of Engineers, Australia.
The Royal Society of New South Wales.
The Australian Chemical Institute.

The Centenary was also celebrated on the 4th September at the conversazione held at the Victoria University College, Wellington, New Zealand, to which all the members of the Institution and of the New Zealand Society of Civil Engineers resident in the neighbourhood of Wellington, and also the general public, were invited. The attendance numbered about 500. Addresses were delivered by Mr. M. Cable, Prof. Florance, Mr. A. Gibbs and Mr. W. H. Gregory, and a number of demonstrations were also given, including 2-way conversation by radio-telephony across the Tasman Sea to Australia.

Celebrations were also held on the 31st August at the Queensland University, Brisbane. The local members of the Institution of Electrical Engineers co-operated with the Royal Society of Queensland, and the following addresses were delivered:—

"Michael Faraday—Biographical Sketch," by Mr. H. A. Longman.
"Faraday as a Physicist," by Prof. T. Parnell, M.A.
"The Chemical Aspects of Faraday's Work," by Prof. L. S. Bagster, D.Sc.
"The Engineering Aspects of Faraday's Work," by Mr. J. S. Just.

Journal Illustrations and Lantern Slides.

The Council strongly deprecate the inclusion of names of firms either in the figures and other illustrations of papers presented to the Institution or in lantern slides exhibited at meetings.

Discussions at Meetings.

The Council also desire to remind members that verbal contributions to the discussions at meetings should not be read from manuscript, the view being held that the presentation of remarks in this manner is contrary to the true spirit of a "discussion," and that contributions in manuscript should more appropriately be sent to the Secretary for publication in the *Journal* as "communicated remarks."

Congrès International d'Électricité de 1932.

The Institution has set up a British National Committee to organize the British effort in connection with the Congrès International d'Électricité de 1932, which will be held in Paris in July, 1932. The object of the Congress is the celebration of the 50th anniversary of the first International Electricity Congress which took place in Paris in 1881, when fundamental and far-reaching decisions regarding electrical units were arrived at.

Prize for Papers by Students, and Graduates under the Age of 28.

A further Students' Prize (value £5) will be awarded this session for the best paper submitted by a Student, or a Graduate under the age of twenty-eight, on the subject of "The Relations between Economics and Engineering."

Papers submitted for the Prize must reach the Secretary not later than the 1st May, 1932. All papers submitted must have been specially written for the purpose, and must not have previously been read or published elsewhere.

The Council reserve the right to postpone the award and, if necessary, to open a fresh competition in the event of none of the papers submitted being sufficiently meritorious.

Scholarships.

The following scholarships have been awarded for 1931–32:—

Ferranti Scholarship (*Annual Value* £250; *tenable for two years*).

W. G. Thompson, B.Sc. (Armstrong College, Newcastle-on-Tyne)

Duddell Scholarship (*Annual Value* £150; *tenable for* 3 *years*).

C. H. W. Clark (Sevenoaks Grammar School).

Silvanus Thompson Scholarship (*Annual Value* £100, *plus tuition fees*; *tenable for* 2 *years*).

C. H. Lackey (Messrs. A. Reyrolle and Co., Ltd.).

David Hughes Scholarship (*Value* £100; *tenable for* 1 *year*).

G. L. d'Ombrain [City and Guilds (Engineering) College].

Salomons Scholarship (*Value* £100; *tenable for* 1 *year*).

S. H. Padel (Manchester College of Technology).

Paul Scholarship (*Annual Value* £50; *tenable for* 2 *years*).

W. T. Darwin (L.C.C. School of Engineering and Navigation).

Thorrowgood Scholarship (*Annual Value* £25; *tenable for* 2 *years*).

P. W. Ottley (Underground Electric Railway Co. of London, Ltd.)

War Thanksgiving Education and Research Fund (No. 1).

Grants of £50 each have been made for 1931–32 to the following for research purposes:—

F. J. Clark (East London College).
J. H. Wagstaff (University College, London).

Annual Exhibition of Electrical and Physical Apparatus.

The 22nd Annual Exhibition of electrical, optical and other physical apparatus, organized jointly by the Physical Society and the Optical Society, will be held on the 5th, 6th and 7th January next at the Imperial College of Science and Technology, South Kensington. There will be a trade section, a research and experimental section, and a section for the work of apprentices and learners.

Members of the Institution desirous of visiting the exhibition should apply to the Secretary (I.E.E.) for tickets of admission.

Overseas Advisory Committees, 1931–32.

The constitution of the Local Advisory Committees abroad is as follows for 1931–32:—

INDIA.

Mr. H. Burkinshaw.
Mr. H. J. Darling.
Mr. P. G. Moore.
Mr. W. H. C. Prideaux.
Mr. S. W. Redclift.
Mr. F. O. J. Roose.
Mr. C. C. T. Eastgate (*Hon. Secretary*).

NEW SOUTH WALES.

Mr. J. E. Donoghue (*Chairman and Hon. Secretary*).
Sir John H. Butters, C.M.G., M.B.E.
Mr. L. F. Burgess, M.C.
Mr. E. F. Campbell, B.Eng.
Mr. R. V. Hall, B.E.
Mr. A. S. Herbert.
Mr. W. J. McCallion, M.C.
Mr. J. K. MacDougall.
Prof. J. P. V. Madsen.

QUEENSLAND.

Mr. W. M. L'Estrange (*Chairman and Hon. Secretary*).
Mr. W. Arundell.
Dr. A. Boyd.
Mr. J. S. Just.
Mr. F. Walker.

SOUTH AUSTRALIA.

Mr. F. W. H. Wheadon (*Chairman and Hon. Secretary*).
Mr. E. V. Clark.
Mr. J. S. Fitzmaurice.
Mr. W. G. T. Goodman.
Mr. W. Inglis.
Mr. P. Kennedy.
Mr. D. E. McLaren.

VICTORIA AND TASMANIA.

Mr. H. R. Harper (*Chairman and Hon. Secretary*).
Mr. W. H. Alabaster.
Mr. F. W. Clements.
Mr. J. M. Crawford.
Mr. T. P. Strickland.
Mr. R. J. Strike.

WESTERN AUSTRALIA.

Mr. J. R. W. Gardam (*Chairman*).
Mr. W. H. Taylor.
Prof. P. H. Fraenkel, B.E. (*Hon. Secretary*).

NEW ZEALAND.

Mr. R. H. Bartley.
Mr. M. C. Henderson.
Mr. E. Hitchcock.
Mr. F. T. M. Kissel, B.Sc.
Mr. A. C. Owen (*Hon. Secretary*).

TRANSVAAL.

Mr. J. B. Bullock.
Mr. S. E. T. Ewing.
Mr. V. Pickles.
Mr. B. Price.
Prof. O. R. Randall, Ph.D., M.Sc.
Mr. W. Elsdon Dew (*Hon. Secretary*).

Committees, 1931-32.

Among the Committees appointed* by the Council for 1931-32 are the following:—

Informal Meetings Committee.

Mr. W. E. Bradshaw (*Chairman*).

Mr. C. H. Flower.
Mr. R. Grierson.
Mr. A. G. Hilling.
Mr. J. J. McKichan.
Mr. H. M. Proud.
Mr. W. A. Ritchie.
Dr. A. Rosen, B.Sc.(Eng.).
Mr. J. F. Shipley.

And

A representative of the General Purposes Committee.
The Chairman of the Papers Committee.
The Chairman of the London Students' Section.

Joint Committee for National Certificates and Diplomas in Electrical Engineering (England and Wales).

Mr. J. M. Kennedy Prof. E. W. Marchant, D.Sc. Prof. E. Wilson	representing the I.E.E.
Dr. F. T. Chapman Dr. A. Morley Dr. C. F. Smith	representing the Board of Education.

Joint Committee for National Certificates and Diplomas in Electrical Engineering (Scotland).

Prof. G. W. O. Howe, D.Sc. Mr. S. Mavor Mr. Robert Robertson, B.Sc. Prof. S. Parker Smith, D.Sc.	representing the I.E.E.
Dr. J. S. W. Boyle Mr. J. G. Frewin Mr. W. Hyslop Mr. F. W. Michie	representing the Scottish Education Department.

Library and Museum Committee.

Col. A. S. Angwin, D.S.O., M.C.
Col. R. E. Crompton, C.B.
Mr. E. W. Hill.
Mr. F. C. Knowles.
Col. Sir Thomas F. Purves, O.B.E.
Dr. E. H. Rayner, M.A.

Local Centres Committee.

Mr. A. Ellis.
Mr. A. L. Lunn.
Col. Sir Thomas F. Purves, O.B.E.
Mr. R. H. Schofield.
Mr. E. E. Sharp.
Mr. B. Welbourn.

And the Chairman of each Local Centre and Sub-Centre.

Meter and Instrument Section Committee.

Mr. F. C. Knowles (*Chairman*).

Mr. G. A. Cheetham.
Dr. C. V. Drysdale, O.B.E.
Mr. F. A. East, B.Sc.(Eng.).
Mr. E. Fawssett.
Mr. A. J. Gibbons.
Mr. E. W. Hill.
Mr. Wilfred Holmes.
Mr. W. Lawson.
Mr. E. H. Miller.
Mr. F. E. J. Ockenden.
Mr. B. A. Robinson.
Mr. E. E. Sharp.
Mr. R. S. J. Spilsbury.

And the Chairman of the Papers Committee.

"Science Abstracts" Committee.

Mr. T. G. N. Haldane, M.A.
Mr. W. M. Mordey.
Mr. C. C. Paterson, O.B.E.
Mr. R. S. Whipple.

Dr. A. Ferguson Dr. D. Owen	representing the Physical Society of London.

Ship Electrical Equipment Committee.

Mr. A. G. S. Barnard.
Major B. Binyon, O.B.E., M.A.
Mr. J. H. Collie.
Mr. S. Harcombe, M.A., B.Sc.
Mr. A. Henderson.
Mr. J. F. W. Hooper.
Mr. P. V. Hunter, C.B.E.
Mr. J. W. Kempster.
Mr. S. W. Melsom.
Mr. N. W. Prangnell.
Col. A. P. Pyne, R.A. (T.A. Res.).
Mr. T. A. Sedgwick.
Mr. F. H. Whysall.
Mr. H. D. Wight.
Mr. E. T. Williams, O.B.E.

And	*Representing*
Mr. A. E. Laslett, I.S.O. Mr. W. McAuslan	Board of Trade.
Mr. H. C. Hazel	Electrical Contractors' Association.
Mr. J. Carnaghan Mr. H. Ruck Keene	Lloyd's Register of Shipping.

And	*Representing*
Mr. A. B. Stewart	Lloyd's Underwriters' Association.
Mr. James Barr Mr. T. R. Thomas	British Corporation Register of Shipping and Aircraft.
Mr. J. Lowson	Institution of Engineers and Shipbuilders in Scotland. Electrical Contractors' Association of Scotland.
Mr. A. W. Stewart	Institution of Naval Architects.
Mr. W. S. Wilson	N.E. Coast Institution of Engineers and Shipbuilders.

Wireless Section Committee.

Chairman: Colonel A. S. Angwin, D.S.O., M.C., B.Sc.
Vice-Chairman: Mr. L. B. Turner, M.A.

Mr. R. H. Barfield, M.Sc.
Mr. G. W. N. Cobbold, B.A.
Mr. H. Faulkner, B.Sc.
Mr. A. J. Gill, B.Sc.
Prof. J. T. MacGregor-Morris.
Prof. E. Mallett, D.Sc.
Mr. B. E. G. Mittell.
Mr. W. J. Picken.
Mr. L. C. Pocock, M.Sc.
Dr. E. H. Rayner.
Mr. E. H. Shaughnessy, O.B.E.
Mr. G. Shearing, B.Sc.
Mr. T. Wadsworth.

The Chairman of the Papers Committee.

And the following representatives of Government Departments:

Admiralty: Capt. J. W. S. Dorling, R.N.
Post Office: Colonel A. S. Angwin, D.S.O., M.C., B.Sc.
Air Ministry: Mr. F. S. Barton, M.A., B.Sc.
War Office: Major J. R. Carter, O.B.E.

Wiring Regulations Committee.

Mr. Ll. B. Atkinson.
Mr. W. J. Bache.
Mr. H. J. Cash.
Mr. J. R. Cowie.
Col. R. E. Crompton, C.B.
Mr. P. Good.
Mr. R. Grierson.
Mr. J. F. W. Hooper.
Mr. H. Marryat.
Mr. S. W. Melsom.
Mr. F. W. Purse.
Col. A. P. Pyne.
Mr. E. Ridley.
Mr. L. Romero.
Mr. J. W. J. Townley.

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* The President is, *ex-officio*, a member of all Committees of the Institution.

Wiring Regulations Committee—*continued.*

And	*Representing*
Mr. W. Lang	Association of Supervising Electrical Engineers.
Mr. H. W. Couzens	Association of Consulting Engineers.
Mr. E. G. Batt Mr. H. H. Berry Mr. F. Broadbent Mr. J. R. Dick, B.Sc. Mr. A. R. Everest	British Electrical and Allied Manufacturers' Association.
Mr. W. F. Bishop	Cable Makers' Association.
Mr. W. R. Rawlings Mr. E. A. Reynolds	Electrical Contractors' Association.
Mr. R. A. Ure	Electrical Contractors' Association of Scotland.
Mr. J. Howard-Blood Mr. E. B. Hunter Mr. W. B. Trafford	Fire Offices Committee.
Mr. R. W. L. Phillips Mr. W. C. P. Tapper	Incorporated Municipal Electrical Association.
Mr. E. W. Farr	Independent Cable Makers' Association.

Representatives of the Institution on Other Bodies.

The following is a list of representatives of the Institution on other bodies, and the dates on which they were appointed:—

Bristol University:

Mr. H. F. Proctor (8 Jan., 1925).

British Cast Iron Research Association:

Mr. E. B. Wedmore (25 Sept., 1924).

British Electrical and Allied Industries Research Association:

Mr. J. M. Donaldson, M.C. (8 Nov., 1928).
Mr. C. P. Sparks, C.B.E. (20 Nov., 1924).

Sectional Committee on Electric Control Apparatus Research:—

Major H. C. Gunton (2 Feb., 1921).
Mr. W. E. Highfield (19 Mar., 1925).

Sub-Committee on Connections to Large Gas-filled Lamps:—

Mr. C. C. Paterson, O.B.E. (24 Oct., 1929).
Mr. B. Welbourn (24 Oct., 1929).

Sub-Committee on Earthing and Earth Plates:

Mr. S. W. Melsom (31 Jan., 1930).

British Electrical Development Association:

Dr. A. H. Railing (5 Feb., 1931).
Mr. T. Roles (13 Feb., 1930).
Mr. H. T. Young (16 Feb., 1928).

Advisory Exhibition Committee:—

Mr. Ll. B. Atkinson (30 Sept., 1926).

Electric Vehicle Committee:

Col. R. E. Crompton, C.B. (22 Oct., 1925).
Mr. W. R. Rawlings (22 Oct., 1925).

Sub-Committee on Constitution:

Mr. J. M. Donaldson, M.C. (4 Dec., 1925).

Sub-Committee on Rural Electrical Development:

Mr. J. M. Donaldson, M.C. (20 Oct., 1927).
Mr. R. Grierson (20 Oct., 1927).

British Standards Institution:

Council:

Mr. Ll. B. Atkinson (21 Jan., 1926).
Col. R. E. Crompton, C.B. (21 Jan., 1926).
Mr. C. P. Sparks, C.B.E. (21 Jan., 1926).

Electrical Industry Committee:

Dr. W. H. Eccles, F.R.S. (17 Feb., 1927).
Lt.-Col. K. Edgcumbe, T.D., R.E.T.(Ret.) (5 Mar., 1925).
Mr. F. Gill, O.B.E. (21 May, 1914).
Mr. J. S. Highfield (21 May, 1914).
Mr. R. T. Smith (21 May, 1914).
Mr. W. B. Woodhouse (19 Dec., 1918).

Technical Committee on Electric Power Cables:

Mr. S. W. Melsom (10 Jan., 1930).

Technical Committee on Electrical Accessories:

Mr. H. J. Cash (31 Mar., 1925).
Mr. F. W. Purse (31 Mar., 1925).

Technical Committee on Electrical Instruments:

Lt.-Col. K. Edgcumbe, T.D., R.E.T. (Ret.) (15 Feb., 1923).

Technical Committee on Electrical Nomenclature and Symbols:

Mr. C. C. Paterson, O.B.E. (8 Jan., 1920).

Technical Committee on Electricity Meters:

Mr. A. J. Gibbons (28 Mar., 1930).
Mr. S. W. Melsom (21 Jan., 1926).
Mr. G. F. Shotter (28 Feb., 1929).

Technical Committee on Letter Symbols:

Mr. A. T. Dover (21 Nov., 1929).

Technical Committee on Overhead Transmission Lines Material:

Mr. P. Rosling (5 Mar., 1925).

Technical Committee on Standardization of Wireless Apparatus and Components:

Mr. E. H. Shaughnessy, O.B.E. (30 Sept., 1925).

Sub-Committee on Conduit Fittings:

Mr. H. J. Cash (18 May, 1927).

Sub-Committee on Connectors for Radio Apparatus:

Mr. R. W. L. Phillips (6 Jan., 1931).

Sub-Committee on Distribution Boards:

Mr. E. B. Hunter (25 Feb., 1927).
Mr. S. W. Melsom (25 Feb., 1927).

Sub-Committee on Low-Voltage Cut-outs:

Mr. H. J. Cash (22 June, 1926).
Mr. E. B. Hunter (25 Feb., 1927).
Mr. S. W. Melsom (25 Feb., 1927).

Sub-Committee on Mains Supply Apparatus:
Mr. R. W. L. Phillips (11 Dec., 1930).
Mr. F. W. Purse (16 Oct., 1928).

Sub-Committees on Switches, Ceiling Roses, Wall-plug Sockets and Connectors for Portable Apparatus:
Mr. H. J. Cash (23 Jan., 1924).
Mr. F. W. Purse (23 Jan., 1924).

Sub-Panel on Graphical Symbols for Interior Installations:
Mr. J. R. Cowie (13 Nov., 1924).

Illumination Industry Committee:
Lt.-Col. K. Edgcumbe, T.D., R.E.T. (Ret.) (28 Feb., 1924).
Mr. P. Good (28 Feb., 1924).
Mr. H. T. Harrison (28 Feb., 1924).
Prof. J. T. MacGregor-Morris (28 Feb., 1924).
Mr. J. M. G. Trezise (19 Mar., 1925).

Technical Committee on Electric Signs:
Mr. L. Barlow (14 May, 1931).

Technical Committee on Engine Testing Fittings:
Mr. W. M. Selvey (22 Oct., 1931).

Technical Committee on Coal:
Mr. W. M. Selvey (19 Jan., 1928).

Technical Committee on Colliery Requisites:
Mr. C. T. Allan (3 July, 1924).

Birmingham Regional Committee:
Mr. F. C. Hall.

Glasgow Regional Committee:
Mr. F. Anslow.

Manchester Regional Committee:
Mr. W. T. Anderson.

Newcastle Regional Committee:
Mr. S. A. Simon.

Sheffield Regional Committee:
Mr. M. Wadeson.

Technical Committee on Land Boilers:
Mr. W. E. Highfield (2 July, 1931).

Technical Committee on Pipe Flanges:
Mr. W. M. Selvey (14 April, 1921).

Technical Committee on Pump Tests:
Mr. R. S. Allen (2 July, 1931).

Technical Committee on Railway Signalling Apparatus:
Mr. A. F. Bound (24 Oct., 1929).

Technical Committee on Rating of Rivers:
Mr. G. K. Paton (20 Oct., 1927).

Technical Committee on Rubber Belting:
Mr. C. Rodgers, O.B.E., B.Sc., B.Eng. (5 Jan., 1928).

Technical Committee on Standardization of Fans:
Mr. R. O. Kapp (22 Oct., 1931).

Sub-Comiittee on Mining Electrical Plant:
Mr. A. C. Sparks (27 Mar., 1930).

Sub-Committee on Portable Railway Track:
Mr. R. T. Smith (25 Oct., 1928).

Sub-Commitee on Tubular Tramway Poles:
Mr. T. L. Horn (4 Feb., 1926).

Petroleum Industry Committee:
Mr. H. W. Clothier (1 Feb., 1923).

City and Guilds of London Institute, Fellowship Committee
Dr. W. H. Eccles, F.R.S. (19 April, 1928).

City and Guilds of London Institute—Telegraphy, Telephony and Radio Communication Advisory Committee:
Mr. E. H. Shaughnessy (22 Oct., 1931).

Council for the Preservation of Rural England:
Mr. J. M. Kennedy (10 Jan., 1929).

Engineering Joint Council:
Col. Sir Thomas F. Purves, O.B.E. (24 Oct., 1929).
Sir Archibald Page (2 Feb., 1928).

Imperial College of Science and Technology, Governing Body:
Mr. W. M. Mordey (12 April, 1923).

Imperial Minerals Resources Bureau Conference, Copper Committee:
Mr. B. Welbourn (18 Sept., 1919).

Institute of Metals, Corrosion Research Committee:
Mr. W. M. Selvey (19 July, 1923).

Institution of Civil Engineers, Engine and Boiler Testing Committee:
Mr. R. A. Chattock (19 Oct., 1922).
Mr. C. P. Sparks, C.B.E. (19 Oct., 1922).

International Association for Testing Materials:
Mr. J. M. Kennedy (5 July, 1928).

International Illumination Commission, British National Illumination Committee:
Lt.-Col. K. Edgcumbe, T.D., R.E.T. (Ret.) (27 Nov., 1913).
Mr. P. Good (18 Sept., 1919).
Mr. H. T. Harrison (27 Nov., 1913).
Prof. J. T. MacGregor-Morris (27 Nov., 1913).
Mr. J. M. G. Trezise (19 Mar., 1925).

Leeds Municipal Technical Library Committee:
Mr. W. B. Woodhouse (19 Dec., 1918).

Loughborough Technical College, Advisory Committee:
Mr. Ll. B. Atkinson (11 April, 1929).

Metalliferous Mining (Cornwall) School, Governing Body:
Mr. L. A. Hards (1 Dec., 1927).

Middlesbrough Technical College, Governing Body:
Mr. E. Edwards (1 Oct., 1925).
Mr. J. M. Gibson (1 Oct., 1925).

National Certificates and Diplomas in Electrical Engineering, Joint Committee (England and Wales):
Mr. J. M. Kennedy (5 Nov., 1931).
Prof. E. W. Marchant, D.Sc. (5 Jan., 1928).
Prof. E. Wilson (5 Nov., 1931).

National Certificates and Diplomas in Electrical Engineering, Joint Committee (Scotland):
Prof. G. W. O. Howe, D.Sc.
Mr. S. Mavor.
Mr. R. Robertson, B.Sc.
Prof. S. Parker Smith, D.Sc.

National Physical Laboratory, General Board:
Dr. W. H. Eccles, F.R.S. (21 Oct., 1926).
Col. Sir Thomas F. Purves (21 Nov., 1929).

National Register of Electrical Contractors:
Mr. H. J. Cash (12 March, 1931).
Mr. P. V. Hunter, C.B.E. (18 Feb., 1926).
Mr. W. R. Rawlings (18 Feb., 1926).
Mr. W. M. Selvey (18 Feb., 1927).

Professional Classes Aid Council:
Mr. P. F. Rowell (20 April, 1928).

Radio Manufacturers' Association, Committee on Battery Eliminators:
Mr. J. R. Dick, B.Sc. (3 April, 1928).

Royal Engineer Board:
Mr. W. B. Woodhouse (19 Mar., 1925).

Royal Society:
Alloys of Iron Research Committee:
Mr. J. Swinburne, F.R.S. (15 Feb., 1923).

National Committee on Physics:
Mr. C. C. Paterson, O.B.E. (6 Nov., 1930).

National Committee on Radio-Telegraphy:
Prof. C. L. Fortescue, O.B.E., M.A. (20 Oct., 1927).
Mr. E. H. Shaughnessy, O.B.E. (6 Nov., 1930).

Science Museum, South Kensington, Advisory Council:
Mr. W. M. Mordey (10 April, 1930).

Smoke Abatement League of Great Britain:
Mr. H. C. Lamb (8 April, 1926).
Mr. S. J. Watson (8 April, 1926).

Technical and Economic Advisory Council for the Building Industry:
Mr. F. W. Purse (2 July, 1931).

Union of Lancashire and Cheshire Institutes (Panel for Engineering):
Mr. A. P. M. Fleming, C.B.E., M.Sc. (28 Feb., 1924).
Prof. Miles Walker, D.Sc. (28 Feb., 1924).

War Office Mechanical Warfare Board:
Dr. W. H. Eccles, F.R.S. (19 Jan., 1928).

Women's Electrical Association:
Mr. A. P. M. Fleming, C.B.E., M.Sc. (18 Dec., 1924).

Women's Engineering Society:
Mr. A. P. M. Fleming, C.B.E., M.Sc. (25 Sept., 1924).

Committee for Training of Women Demonstrators:
Mr. E. E. Sharp (5 Nov., 1931).

World Power Conference (British National Committee):
Mr. Roger T. Smith (12 March, 1931).

Elections and Transfers of Members.

At the Ordinary Meeting held on the 5th November, 1931, the following elections and transfers were effected:—

ELECTIONS.

Associate Members.

Bullard, Colin, B.Eng.
Chew, William George N.
Cox, William T.
Cummings, Herbert Leonard.
DuBarry, Eugene Frederick.
Gray, Abel, B.Sc.
Harris, Sydney Charles G.
Hill, John Noel.
Hobley, Frederick Richard.
Hoey, George McCausland, B.A., B.E.
Inman, Thomas Montague.
Jackson, Frank.
Jarrett, Edward Jones.
Jenkin, Peter Ormrod.
Jones, Percy William D., B.Sc.
Kidd, Arthur Godfrey.
Lampert, William Ernest C.
Liggins, William Henry.
Miller, Alexander Alfred L., Lt.-Commdr., R.N.
Mills, Fred.
Milne, Kenneth Harvey.
Nelson, William Anderson.
O'Kelly, Fergus F., B.E., B.Sc.
Rooksby, Randle Harvey.
Seckham, Charles Percy.
Shirt, Daniel James E.
Simpson, John.
Skillington, George Eric.
Smith, James Frederick.
Taylor, Ernest.
Thouless, Kenneth James, M.A.
Wallace, John Malcolm.
Worlledge, John Penry G., Lt.-Col., O.B.E., R.S.

Companion.

Sandmeier, Ernest G.

Associates.

Angell, Henry Baron.
Bond, Clement Dickson.
Cousins, William George.
Dyer-Smith, Harold Edward.
Hill, Joseph.
Laird, James Roy.
Lewis, Albert.
Miles, Herbert.
Walker, Harold Preston.
Wood, James Adie B.

Graduates.

Allen, Leslie Leonard.
Atkinson, Richard Scott.
Bach, Charles Ellis.
Balfour, Lionel Maxwell J., B.A.
Bocock, William Arthur.
Brockbank, Philip Edward, M.Sc.
Brown, Alexander Blair.
Brown, Louis Robertson.
Chart, Aubrey Vivian, R.N.
Cheetham, Harry.
Cooke, Charles Harry C.
Duggan, William Armon.
Fletcher, Norman Barry, B.Sc.Tech.
Griffiths, Eric William S., M.A.
Harcombe, Tudor Emlyn, B.Sc.(Eng.).
Hext, Frederick Maurice, Lieut., R.E.
Howarth, Fred.
Hughes, George Ernest.
Jeffcock, Robin John P.
Jones, Albert Enoch.
Moona, Lakshmi Narayan.
Nock, Oswald Stevens, B.Sc.(Eng.)
O'Connell, John, B.E.
Raine, John Clitheroe.
Redman, John Robert.
Rees, Trevor, B.A.
Robertson, Harold Swinbourn, B.Sc.
Smith, Leslie Vere.
Thomas, Harry.
Tiley, Mark.
Wray, Stanley Horace.
Young, Reginald Hackworth, B.Sc.(Eng.).

Students.

Absolom, Norman Glass.
Akroyd, Ian.
Anderson, Ian Lind.
Baker, George Albert.
Barnard, Ernest Walter.
Barratt, Gordon Herbert.
Barry, Robert Francis.
Bebianno, Attila.
Bingham, George Stanley.
Bishnoi, Guru Dutta.
Borgars, Sydney John.
Carr, David Livingstone.
Celly, Des Raj.
Chaudhry, Shyam Sarup.
Clark, Colin Henry W.
Cochrane, Derek Leslie.
Cross, Arthur.
Cross, William Russell
Das, Benoy Krishna.
Forby, Kenneth George.
Garbutt, Arthur William N.
Garrett, Reginald.
Gill, John Barnes.
Gillespie, Miles Lamport, B.Sc.
Greer, Norman Campbell.
Hendry, Norman.
Heppenstall, Frank Evelyn, B.Sc.(Eng.).
Jacobs, Paul Geoffrey.
James, Leslie Gasper.
Kaul, Jai Nath, M.Sc.
Kavanagh, Henry P.
Kennemore, Haydn.
Khanna, Ram Charan L.
Kucera, Frank L.
Lackey, Clemett Harrison.
Midgley, Albert Morrell.
Neill, William Oswald.
Ottley, Philip William.
Padel, Stuart Hunter.
Pathak, Lakshman Dev.
Pawley, Gordon Frank.
Price, Sidney.
Radwan, Abdel-Hafeez M.
Ramanujacharya, Komanduri.
Sahgal, Premlal.
Singh, Ranjit.
Smith, Arthur.
Smith, Dick,
Snow, Richard William.
Stork, Kenneth Bertram.
Sujan, Vishindas Bagomal.
Swami, Teegala Venkateswara.
Thorp, Albert.
Toft, Patrick William.
Townsend, Eric Henry.
Tropper, Hans.
Tweedie, Leslie Oscar.
Vij, Kasturi Lal.
Walker, Alan Maxwell.
Welsh, Joseph.
Wilen, James Allan.
Withington, Harry.
Wooldridge, Frederick John.

TRANSFERS.

Associate Member to Member.

Ayres, William Edward M.
Cooke, Walter Henry.
Grapes, Herbert John.
Haldane, Thomas Graeme N., M.A.
Howarth, Oliver.
Lloyd, William Francis, M.A.
Nelson, James Egar.
Wright, Ratcliffe.

Associate to Associate Member.

Cook, James William D.
Freeth, Lancelot Gerhard.
Gibson, Franklin Henry.
Haws, John Hayward.
Hofman, Stanislas.
Jones, Edward.
Landers, Marshall Arthur B.
McPherson, Angus.
Mitchell, James, B.Sc.(Eng.).
Mylchreest, Henry William.
Pugh, Harold Valentine.
Wright, Eric Percival, B.Sc.

Graduate to Associate Member.

Bhavnani, Hashmatrai Khubchand, B.Sc.Tech.
Bourne, Percival Edwardes
Brown, William John.
Byrne, Francis.
Cooke, George Pearson, B.A.
Crowe, Henry Eyre.
Dommisse, David Rowell.
Escott, Alexander John.
Ganapati, Salem Vencatramana.
Grant, David Leslie.
Guilford, Alfred Leslie, B.Sc.Tech.
Haggart, Andrew, B.Sc.

Graduate to Associate Member—continued.

Hawkings, Reginald John, B.Sc.
Hayman, William George I., B.E., B.Sc.
Hazel, Henry.
Henson, William Joseph R.
Kirkby, Norman Reginald, B.Sc.
Law, John William B.
Lipscomb, Robert, B.Sc.
Menon, K. P. Padmanabh, B.A., B.Sc.
Meyers, Arthur Lennox, B.Sc.(Eng.).
Millward, Gerald Richard.
Murray, Kenneth George.
Patel, Jashbhai Govindbhai.
Phipps, William Alfred.
Price, Arthur Conrad, B.Sc.(Eng.)
Ripley, Ronald Vincent.
Saunders, Norman Frank T., B.Sc.
Thomas, Harold Leslie, B.Sc.(Eng.).
Traynier, Maurice Anthony.
Upasena, Esapala.
Verma, Panna Lal, B.Sc.
West, Harry.
Whittaker, Douglas, B.Sc.
Wood, Norman Ray, M.A.

Student to Associate Member.

Greenwood, Leslie.
Kishk, Mohammed, B.Sc.(Eng.).
Nind, Eric Arthur, B.Sc.(Eng.).
Perry, Fergus Roy M.Sc.Tech.
Roche, Alleman Holly, B.Sc.(Eng.).
Wittrick, James Lewis.

The following transfers have also been effected by the Council:—

Associate to Graduate.

Donaldson, Thomas.
Lamb, James Forrest.
Mitchell, Thomas Alfred.

Student to Graduate.

Abrahams, Hyman Harold.
Advani, Gurmukhsing Awatsing.
Advani, Motiram Hotchand.
Ainsworth, Frank Glave, M.Eng.
Ali, Syed Nazeer.
Allen, Douglas Charles.
Allen, Robert Girdlestone.
Allwood, Albert Wilfred, B.Sc.
Anderson, John Rupert.
Andrews, Desmond.
Arbour, William Frederick.
Baber, Frederick James.
Baird, David.
Barrett, Arthur Edwin, B.A.
Baxter, Herbert Edward.
Bayton, John Haggitt.
Beckingsale, Alec Alfred.
Beggs, David Norman, B.Sc.Tech.
Bellchambers, Harold Edgar.
Bentley, Robert.
Bloor, Reginald Morris.
Bowdler, William.
Bowles, Charles.
Bramwell, Clifford.
Brayshaw, George Stanley, B.Sc.(Eng.).
Brewin, James Edward.
Bridger, William.
Burge, Randolph Albert, B.Sc.(Eng.).
Burr, Donald William.
Calder, Rex Finlayson C. B.E.
Campbell, Allan.
Carr, Thomas Henry.
Carter, John.
Cathcart, David McLaren, B.Sc.
Caton, George.
Channon, Derek Harry W., M.Sc.(Eng.).
Clark, Ernest.
Clark, Reginald Erskine.
Colvin-Smith, Peter Molison.
Cook, Arthur, B.Sc.(Eng.).
Cox, Cecil Louis.
Cubitt, Roger Harry, B.Sc.(Eng.).
Cuervas, Manuel.
Dancy, Charles Romney.

Student to Graduate—continued.

Davies, Arthur Cyril, B.Sc.(Eng.).
Dinenage, Stanley Charles.
Donkin, John, B.Sc.(Eng.).
Dooley, Arthur.
Downton, Kenneth Edward.
Earnshaw, Eric John, B.A.
Eastwood, Harold.
Elworthy, Bernard Charles T.
England, Charles James.
Fair, John William.
Fairhurst, Austin Joseph.
Fairhurst, Harold Hargreaves, M.Sc.Tech.
Fernley, George.
Finch, Frank Hugh U.
Fouracre, Victor William M.
Gardner, Harry St. George, B.Sc.(Eng.).
Garner, Raymond Hubert.
Goodman, Arthur.
Griffiths, Herbert Albert H.
Groom, Leonard William.
Hamilton, Robert Nelson, B.Sc.(Eng.).
Hammad, Elsayed Helmy.
Hardikar, Ram Ganesh.
Hargreaves, Robert Stewart.
Harman, Harold Arthur.
Harvey, Arthur Frank, B.Sc.
Haskard, John Leslie.
Heaton, William James, B.Eng.
Hill, Norman Ernest G., B.Sc.(Eng.).
Holmwood, Kenneth Arthur.
Holt, Alfred Ifor W.
How, Frank.
Hunt, Norman Herbert.
Hunter, John.
Jacobsen, Bent Bulow, B.Sc.(Eng.).
Jarvis, Charles McKechnie.
Jefferson, John Carnt.
Jensen, Kaj Leo, B.Sc.(Eng.).
Johnson, William James.
Kearns, Thomas.
Keay, Andrew Leslie.
Keays, Hastings de Jersey, B.Sc.
Kelly, Richard Gould.
Kerridge, Kenneth Elliott.
Kinder, Ralph Noel.
Kishen, Bal.
Knight, Reginald Frederick.
Lambert, Joseph Ernest.
Law, Lawrence Brian.
Laycock, Leonard Spencer.
Lett, Frederic Tom.
Leverton, John Henry, B.Sc.(Eng.).
Lissimore, John Philip, B.Sc.
Lloyd, Charles Noel.
Longley, Harold Anson.
Macmaster, Malcolm Morrison, B.Sc.
Maddock, Roger Raymond, B.Eng.
Maguire, Charles Richardson, B.Sc.
Marrian, Edward John M., B.Sc.
Martin, Albert George, B.A.
Master, Navntilal Hiralal, B.Sc.

Student to Graduate—continued.

Mather, John Walter S.
May, Eric Borton.
Messenger, Albert Roy.
Middleton, Reginald James P.
Millar, Harold James, B.Sc.(Eng.).
Mills, Harry Douglas.
Moore, Arthur Leslie.
Morley, John Baillie, B.Sc.Tech.
Moxon, Leslie Arnold, B.Sc.(Eng.).
Mumford, William Bevan R.
Murray, Leonard James.
Newman, Percy Laurence.
Nicholson, John.
Nicholson, Mansell Price.
Onley, Eric Thomas F., B.Sc.
Ottman, Percival Algernon, B.Sc.(Eng.).
Parker, Frank Dewar.
Patel, Kantilal Chaturbhai.
Pearse, George Alfred.
Pike, Charles Henry.
Powell, Horace Seymour.
Rice, Richard Henry G.
Richardson, Philip.
Ritchie, Douglas Loudoun, B.Sc.
Robinson, Collinwood.
Rogers, Bernard Henry G.
Rogers, Francis Gordon.
Rogers, John Frederick W.
Rushforth, Leonard, B.Sc.
Ryder, Harold Herbert.
Sadleir, Keith Arthur.
Sagar, Yashpal.
Sengupta, Monoranjam, B.Sc.
Sen Gupta, Narendra Nath, B.Sc.
Shircore, Stephen Osbourne.
Shires, Thomas Atherton.
Shute, Robert Oxenham.
Skinner, Frederick George J.
Smith, Edward Ethelbert M.
Smith, Eric.
Smith, Ralph Balmforth, B.Sc.
Strawson, Thomas Russell.
Stupple, Harold William.
Sumner, John Houghton, B.Sc.Tech.
Sutton, John Evelyn.
Sykes, Clifford, B.Sc.
Tatton, Eric.
Taylor, Harold Frederick R.
Thompson, Henry Christian, B.Sc.
Tombs, David Martineau, B.Sc.(Eng.).
Turner, Dennis Round, B.Eng.
Tyldesley, Arthur.
Velge, George Edgar.
Vos, Laurence Stanley.
Wallace, Norman Mordaunt.
Wallen, Henry.
Watt, James Leslie.
Westlake, Alfred Luigi.
Woodcock, Colin Frederick.
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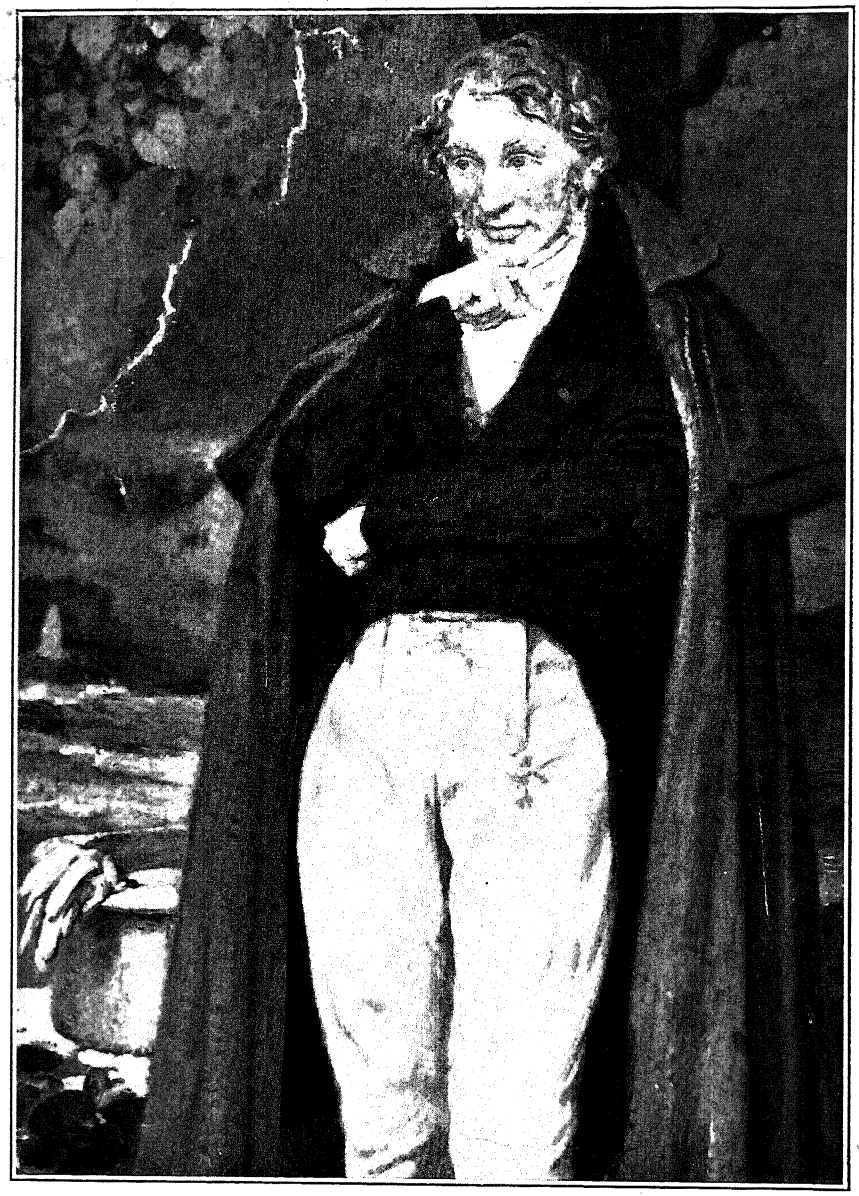

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COIL IGNITION SYSTEMS.

By E. A. Watson, O.B.E., Associate Member.

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SUMMARY.

The paper first deals with the general principles of, and the conditions to be fulfilled by, coil ignition apparatus for internal-combustion engines.

It then describes a simplified treatment of the induction coil, regarded as a closely-coupled system with damping due to secondary loading, an assumption which is found to give results agreeing fairly well with practice.

From this theory is developed a basis of coil design, enabling optimum values to be chosen so as to meet given conditions and indicating the limits which are met under extreme conditions of operation, generally at high engine speeds and low battery voltages.

Methods of extending the range of operation, when necessary, are then dealt with, and special designs are described which have been developed with a view to meeting extreme conditions of operation.

A further section deals briefly with the constructional features of modern coil systems, and with the principal points embodied in the various details.

Four appendices are added giving detailed treatment of various problems, resulting in conclusions which are embodied in the paper itself.

LIST OF SYMBOLS.

The following symbols are used in the body of the paper and in Appendix A. In the other appendices they have the same general meaning, but in some cases where there is no possibility of ambiguity they are used in slightly different applications.

C = equivalent secondary capacitance.
C_1 = capacitance shunting contact-breaker.
C_2 = total capacitance in secondary circuit, including self-capacitance of windings, expressed in terms of a single capacitance across secondary terminals.
D = damping factor = V_1/V_0.
L_2 = inductance of secondary winding with primary open-circuited.
L_1 = inductance of primary winding with secondary open-circuited.
n_1 = number of turns in primary winding.
n_2 = number of turns in secondary winding.
R = resistance of primary winding.
R_2 = total equivalent shunting resistance, calculated on the secondary side.
R_0 = that portion of R_2 representing internal losses in coil.
r = ratio of secondary to primary turns = n_2/n_1.
t = instantaneous time (also used for closed period of contact breaker).
V = instantaneous voltage (also used for voltage of system supplying coil).
V_0 = secondary voltage which would be reached in the absence of damping.
V_1 = value of first secondary-voltage peak.
V_2 = value of second secondary-voltage peak.

INTRODUCTION.

In 1921 the author presented to the Institution* a paper on "Magnetos for Ignition Purposes in Internal-Combustion Engines," which put forward the then existing basis of design and construction of the ignition magneto, practically the only ignition system in use at that time on British and Continental cars.

Since that date the coil or battery ignition system has made considerable headway, both in this country and on the Continent, and is fitted to at least 80 per cent of the motor-cars now being produced. A discussion of the reasons for this change and of the relative advantages of the magneto and the coil system of ignition is outside the province of this paper. Suffice it to say that the chief reasons are the lower cost of the coil system on multi-cylinder engines, the avoidance of difficult problems in the driving of the ignition unit, and the choice of a suitable type of magneto when high-speed engines of six or more cylinders are under consideration. In addition, the growth in the use of electrical auxiliaries, with the consequent necessity of an adequate and properly-maintained battery, has largely removed the great drawback of all coil ignition systems—their dependence upon the battery for the supply of the energy necessary for starting purposes.

The purpose of this paper is to give an outline of the fundamental conditions underlying the design and performance of coil ignition systems, with an indication of the limits which exist to speed of operation and performance under given conditions, and to indicate particularly in what way these conditions may be different for European cars, with their high-speed engines and 12-volt systems, as compared with the lower-speed engines with which 6-volt systems have been operated successfully in the United States for many years past.

CONDITIONS TO BE FULFILLED BY IGNITION SYSTEMS.

It is now generally recognized that the amount of energy delivered in the discharge by the ignition system, whether coil or magneto, bears no direct relation to the energy necessary for ignition of the explosive charge. This latter is in all cases a very small quantity, and the electrostatic energy stored in the capacitance associated with the sparking plugs and cables when these are charged to the sparking voltage is in all cases sufficient to cause ignition, provided that the explosive mixture is of a composition such that it can be effectively employed in the cylinder of an internal-combustion engine. The curves connecting spark energy and mixture strength are U-shaped, but the mixture strengths associated with the two limbs of the U are in general of such a value that even if the range of mixture could be extended slightly, by a totally disproportionate increase in spark energies, the slow rate of burning of the corresponding gaseous mixtures would render them unsuitable for use in any form of internal-combustion engine.

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* *Journal I.E.E.*, 1921, vol. 59, p. 445.

The problem of the ignition unit is simply, therefore, that of providing the energy necessary to raise the secondary system—the capacitance associated with plugs, cables, distributor and a portion of the distributed capacitance of the winding itself—to the sparking potential, while at the same time supplying any leakage which may occur as the result of imperfect insulation of the secondary circuit.

DESCRIPTION OF GENERAL SYSTEM.

While the general arrangement of a typical coil ignition system is probably familiar to the majority of engineers, it may, perhaps, not be out of place to preface a detailed consideration of its operation by a brief summary of the type of apparatus under discussion. Various forms of coil ignition systems have been used in the past, but with one or two exceptions, which are briefly considered at a later stage of the paper, the type of system has virtually become standardized. It consists of a contact breaker driven positively from the power unit, and, in a 4-stroke engine, revolving at half engine-speed, which interrupts the current in the primary of an induction coil, the secondary of which is connected either directly to the sparking plug (in a single-cylinder engine), or through a synchronously-driven distributor (in a multi-cylinder engine). The current in the circuit is interrupted positively at a definite moment by the contact breaker, and the necessary igniting spark occurs approximately 0·0001 second after each interruption. The trembler-coil system, in which the circuit is closed by a synchronously-driven contact maker and interrupted by a contact breaker operated by the coil itself, is at the present time completely obsolete. The contact breaker is usually—in fact, almost invariably—fitted with tungsten contact-points and shunted by a condenser in the usual manner. Such a system, consisting of an inductive circuit repeatedly closed and opened for a series of short time-intervals, naturally takes its maximum current under low-speed conditions—the value of the current interrupted falling as the speed increases. The general problem in any coil ignition system therefore resolves itself into obtaining a value of the interrupted current sufficient to ensure satisfactory ignition, without an excessive current at low speeds and without involving risk of overheating should the ignition circuit be left closed with the engine stationary.

CONSIDERATION OF COIL AS A CLOSE-COUPLED SYSTEM WITH DAMPING.

The complete theory of the induction coil as two coupled circuits has been treated very fully by E. Taylor-Jones,* who has shown that for any given primary and secondary capacitances and inductances there is a degree of coupling which will produce optimum results. Under these conditions the whole of the oscillatory energy in the primary circuit will at one given instant be transferred to the secondary circuit, and appear as electrostatic energy in the secondary capacitance, coincident with the appearance of the oscillatory secondary energy in the same form. This line of argument, if pushed to its logical conclusions, might lead to the development of loosely-coupled coils in which the primary and secondary capacitances were adjusted to correspond to optimum conditions. Such a system would, however, have the great disadvantage that these conditions would only hold for one particular length of high-tension cable and type of sparking plug. A small alteration in these conditions, or a large leak over the insulation, might have the effect of transforming a system adjusted for optimum conditions to one exactly the reverse. Further, it is conceivable that in the event of such changed conditions occurring, a large proportion of the energy would not be transferred to the secondary circuit and dissipated in the spark but would be left in the primary side of the loosely-coupled system, giving rise to possible high values of the voltage at the contact-breaker points and difficulties in securing sparkless interruption of the circuit.

For ignition systems in which the secondary conditions are liable to considerable variation and in which considerable leakage losses may occur, it is believed that a close-coupled design of coil is the best fitted to meet general requirements, and perfect coupling will be assumed in the theory which follows. It is admitted that the coils generally in use are not absolutely close-coupled, although the coefficient of coupling between primary and secondary is usually at least 90 per cent. The fact remains, however, that the results obtained on the basis of close coupling do agree reasonably well with those obtained by tests on actual coils.

In order to simplify treatment, then, the coil will be considered as consisting of the windings P,S, which are closely coupled together and shunted with the primary condenser C_1 and secondary condenser C_2, respectively. The system is also shunted by the resistance R_0, which represents the iron losses in the core. The resistance of the windings themselves will be disregarded; this assumption can be shown to be permissible in view of the heavy damping due to other causes.

Since the windings are closely coupled, we may substitute for the two capacitances C_1 and C_2 a single equivalent capacitance C shunted across the secondary only, C being equal to $C_2 + C_1/r^2$, where r is the ratio of secondary to primary turns. Let L_2 be the inductance of the secondary winding (with the primary open-circuited) and R_2 the total equivalent shunting resistance, made up of R_0 plus the external load. The windings being closely coupled, it is immaterial whether we regard the current as flowing in the primary or the secondary winding, and if we consider the interruption of a current flowing in the latter we can represent the decay of current and the growth of e.m.f. by the equation

$$-L_2\frac{dI_L}{dt} = RI_R = V$$

where I_L and I_R are the instantaneous values of the currents in the inductive and resistive branches of the circuit respectively. This gives us a differential equation of the usual form

$$C\frac{d^2V}{dt^2} + \frac{1}{R_2}\cdot\frac{dV}{dt} + \frac{V}{L_2} = 0$$

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* "The Theory of the Induction Coil" (Pitman), 1st ed., 1921.

representing the decay of current and growth of e.m.f. in a damped inductive circuit. The solution of this equation is given in Appendix A. For values of R_2 less than $\sqrt{(L_2/4C)}$, for which values oscillations occur, the voltage at the first peak V_1 has the value

$$V_1 = V_0 D$$

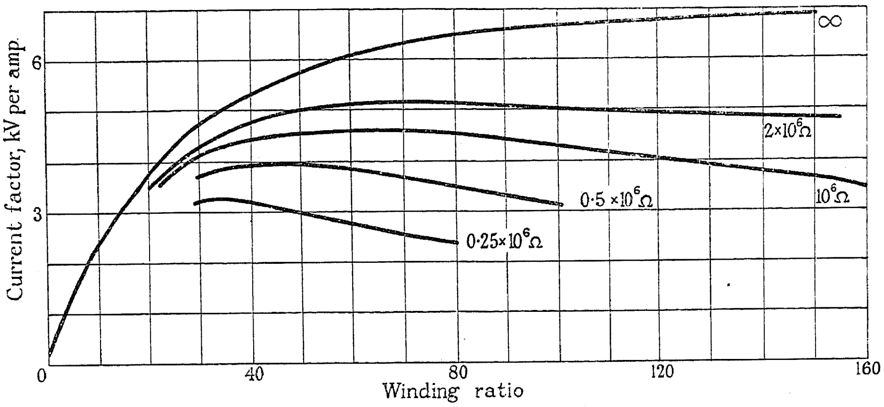

FIG. 1.—Variation of current factor with winding ratio.

$L_1 = 5$ mH; $C_1 = 0{\cdot}12$ μF; $C_2 = 100$ $\mu\mu$F.

where V_0 is the voltage which would be reached in the absence of damping, and D is a damping factor given by the expression

$$D = e^{-\frac{x}{\sqrt{(1-x^2)}}\arccos x}$$

in which $x = \dfrac{1}{2R_2}\sqrt{\left(\dfrac{L_2}{C}\right)}$

The value of V_0, the voltage which would be attained in the absence of damping, may be expressed in terms either of the energy in the system before break, or of the primary current and primary inductance. The two methods of expression are, of course, equivalent; in some cases the former is the more useful, in others the latter. As the primary current is a convenient criterion, however, and as this also is subject to very definite limitations due to contact-breaker phenomena, it is generally more desirable to adopt the latter method of expression. In this case we have, equating electromagnetic and electrostatic energies,

$$\tfrac{1}{2}V_0^2 C = \tfrac{1}{2}I^2 L_1$$

$$V_0 = I\sqrt{(L_1/C)}$$

and $$V_1 = ID\sqrt{(L_1/C)} = I\sqrt{(D^2L_1/C)}$$

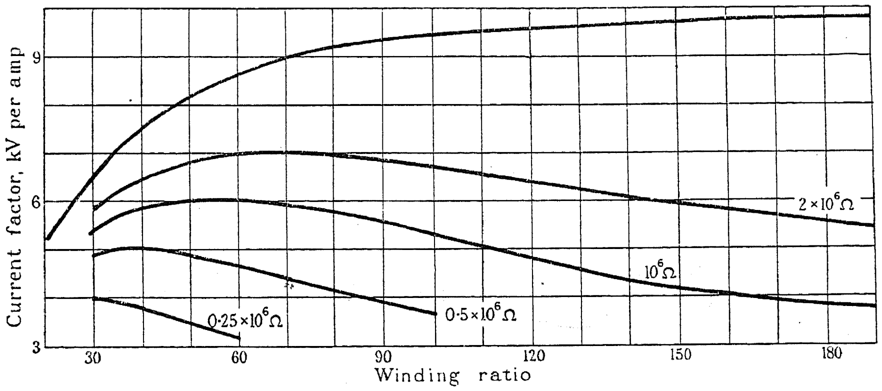

FIG. 2.—Variation of current factor with winding ratio.

$L_1 = 10$ mH; $C_1 = 0{\cdot}12$ μF; $_2 = 100$ $\mu\mu$F.

The quantity $\sqrt{(D^2L_1/C)}$, which may be termed the "current factor" of the coil, expresses the secondary voltage produced in terms of the primary current broken, and may conveniently be stated in units of kV per ampere. It will be clear from the expression that if it were possible to construct a series of coils having equal damping and the same value of C, the "current factor" would be proportional to the square root of the primary inductance, and the secondary voltage would merely be directly proportional to the input energy. Actually, of course, this is impossible, as even if the winding ratio is kept the same when L_1 is varied so as to maintain a constant value of C, the damping factor D, which involves the term $\sqrt{(L_2/C)}$, will change as L_2 is varied; while if the secondary inductance L_2 is held constant while L_1 is altered by changing the number of primary turns, C will vary and with it D also. Considering for a moment a coil of given primary inductance, in which the ratio is varied, it will be clear that if damping due to secondary loading is present such damping must increase with increase of winding ratio and secondary inductance, as a longer period must elapse before the first peak, and in consequence more energy will be dissipated. On the other hand, increase in winding ratio will decrease the value of C, and therefore increase the value of V_0.

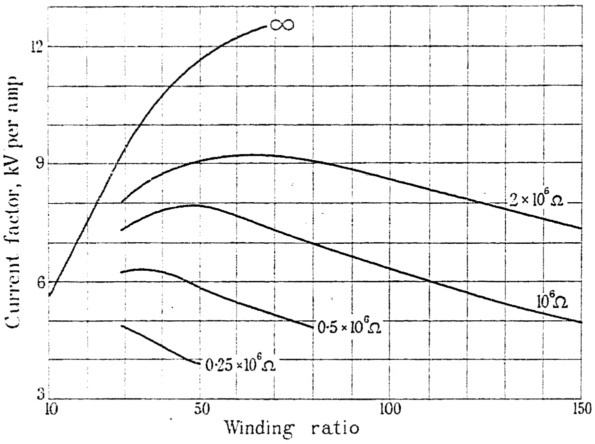

FIG. 3.—Variation of current factor with winding ratio.
$L_1 = 20$ mH; $C_1 = 0{\cdot}12\ \mu$F; $C_2 = 100\ \mu\mu$F.

The combined effect of these is shown in Figs. 1 to 4, which give the values of the current factor calculated for assumed coils for primary inductances of 5, 10, 20, 30 and 40 mH respectively. For these coils the following values have been assumed: $C_1 = 0{\cdot}12\ \mu$F, $C_2 = 100\ \mu\mu$F, R_2 ranging from ∞ to $0{\cdot}25$ MΩ. These values accord with present practice in coil design.

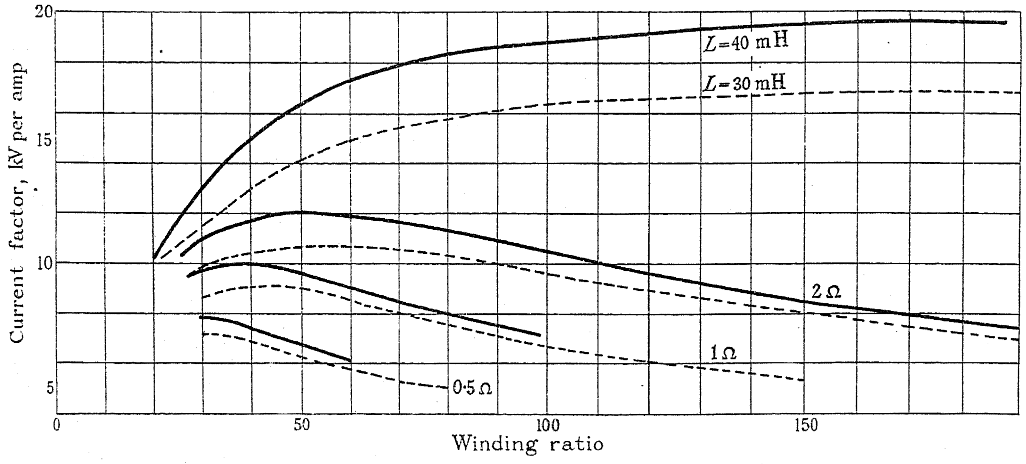

FIG. 4.—Variation of current factor with winding ratio.
$L_1 = 30$ and 40 mH; $C_1 = 0{\cdot}12\ \mu$F; $C_2 = 100\ \mu\mu$F.

It will be noticed that for all cases where damping is present there exists an optimum winding-ratio ranging from between 60 : 1 and 70 : 1 for a primary inductance of 5 mH and a shunting resistance of 2MΩ, to less than 30 : 1 for the higher inductances and lower resistances. It is, of course, a simple matter to select from these the appropriate current factor and ratio for each value of the primary inductance, and thus obtain a series of coils of varying inductance but designed in each case for optimum performance. Fig. 5 shows:—(*a*) The current factor for a series of coils designed to meet open-circuit conditions only. (*b*) The current factor for a series designed to carry a load of 0·5 MΩ, but actually operating on open circuit. (*c*) The current factor for the same series when operating on their designed load of 0·5 MΩ. Comparing curves (*a*) and (*c*), we see that for a coil designed to meet open-circuit conditions only, the current factor increases much more rapidly with increase of primary inductance than it does in the case of a coil which has to deal with secondary resistance loading; in other words, the high-inductance coil is at a disadvantage as compared with the low-inductance coil when it has to work under loaded conditions with a given energy input.

HIGH- AND LOW-SPEED OPERATING CONDITIONS.

In the preceding paragraphs the current factors for a range of coils of varying inductance, but designed for optimum conditions, have been evaluated; and thus, knowing the value of the current broken in the primary circuit, we can at once write down the secondary performance. If the primary current at break is maintained constant, the curve expressing the relation between current factor and inductance also expresses the relation between secondary voltage and inductance. In actual practice, however, the current at break is a function of (*a*) coil resistance, (*b*) battery voltage, (*c*) the time during which the circuit is closed, and (*d*) coil inductance. Of these, the coil resistance is dictated by conditions of heating or arcing at the contact points, but within certain limits it can be varied at will. The other factors are, however, as a rule defined in advance by the particular ignition conditions of the engine under consideration.

To fix our ideas more definitely, let us consider the case shown in Fig. 6, where the upper curve A corresponds to curve (*c*) of Fig. 5. This curve expresses the kV at the secondary terminals of a coil in which a current of

1 ampere is broken, and we will assume that the resistance is such that this current flows when the normal voltage is applied to its terminals and the current is allowed to reach a steady state. Under starting conditions, when the closed period is always sufficient for this condition to be attained, the performance will fall below normal if the battery voltage decreases or the resistance of the coil increases. A fall in battery voltage will, of course, always occur if the engine is started by means of a startor motor, as is almost universal practice at the present time. The extent to which the battery voltage falls under these conditions depends upon the state of the battery and the current taken by the motor, the latter, in turn, depending upon many variable factors—notably the temperature of the engine and the viscosity of the lubricating oil. If the battery is in good condition, and the engine is reasonably free and is provided with a startor motor and battery of adequate size, the voltage will usually fall to about 80 per cent of the normal value. Values as low as 70 per cent or less may, however, be reached under adverse conditions (such as a cold, stiff engine and partly discharged battery) and should be regarded as possible in any ignition system. It is necessary, in addition, to allow for an increase in coil resistance due to heating, such as may occur if the ignition circuit is closed some time before the engine is started. The extreme case is that in which the ignition is inadvertently left on, thus permitting the coil to attain its maximum temperature, and an attempt is then made to start the engine. Under such conditions a coil of the type frequently employed at the present day—in which the whole of the resistance in the primary circuit is provided by the winding itself and no external resistance is used—will occasionally

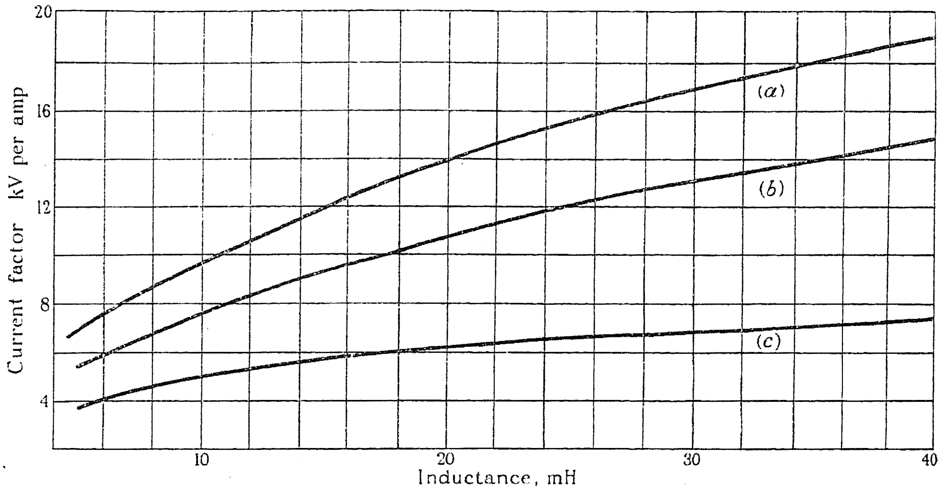

Fig. 5.—Relation of current factor to inductance. Coils designed for following optimum conditions (subject to minimum ratio of 40/l).

(a) No load. (b) 0·5 megohm on no load. (c) 0·5 megohm on load.

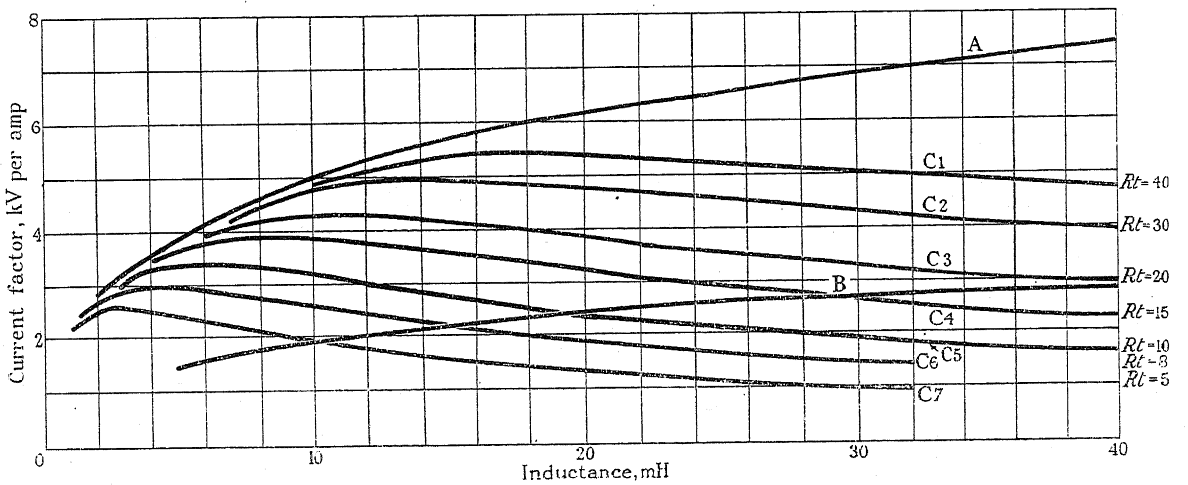

Fig. 6.—Variation of coil performance with primary inductance, resistance and voltage.

$C_1 = 0{\cdot}12\ \mu$F; $C_2 = 100\ \mu\mu$F. Coils designed for 0·5-megohm load.

attain a temperature as high as 120° C., corresponding to a resistance increase of nearly 50 per cent. Extreme conditions, i.e. when the battery voltage drops to 60 per cent of the normal value and the coil resistance rises to 50 per cent above normal, will correspond to a reduction of voltage to 40 per cent of normal without alteration in resistance. This state of affairs is represented in Fig. 6 by curve B, which is merely curve A with its ordinates reduced to 0·4 of their normal value. Curve B will express the secondary kV produced under the adverse conditions postulated above by the interruption of current in the primary of a coil which takes 1 ampere at normal voltage. Having decided what is the maximum secondary voltage demanded by the ignition system, the normal coil-current can be found by dividing this value by the ordinate of curve B at any given point. For example, if 7·5 kV is necessary to ensure operation of the ignition system, the normal standstill current (cold) taken by a coil of 21-mH inductance for which the ordinate of curve B is 2·5 kV, will be 3 amperes.

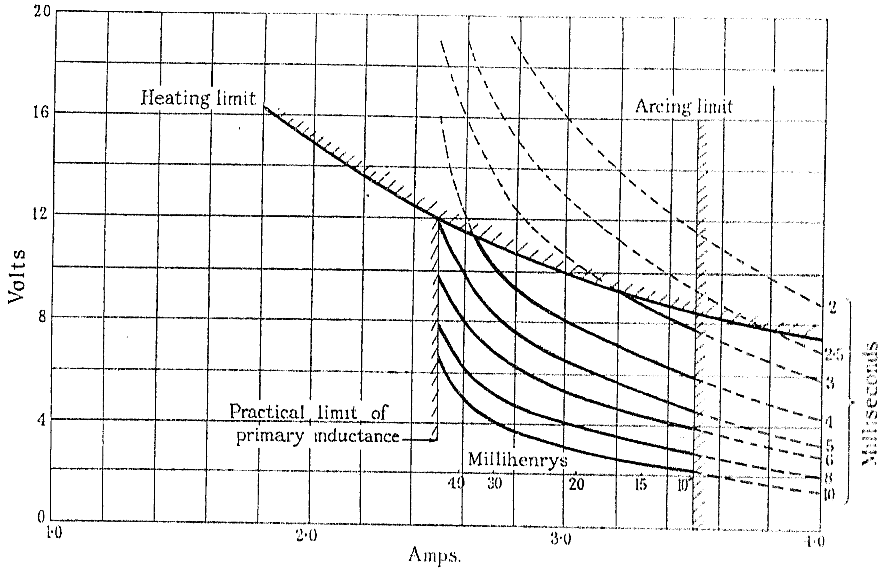

FIG. 7.—Series of coils designed for 0·5-megohm load at 7·5 kV.

$C_1 = 0{\cdot}12\ \mu F$; $C_2 = 100\ \mu\mu F$. Winding ratio optimum for load (subject to limitation of 40/1).

We have next to consider the condition of high-speed operation, when the coil is fed with its normal voltage (under certain conditions, particularly in the day-time, the voltage may be as much as 25 or 30 per cent above normal) but the closed period is short. In this case the current at break will follow the usual law of growth in an inductive circuit, so that for a given time of close the current at break expressed as a fraction of the standstill current will decrease as the inductance increases. This is expressed in Fig. 6, where a series of curves have been plotted for different values of Rt which have been obtained from curve A by multiplying the ordinates by the factor appropriate to each inductance, to allow for the fact that the current has not attained its steady value. These curves all exhibit one interesting point, a maximum value of the secondary voltage corresponding to a definite primary inductance; showing that if the time of close is fixed there is always a corresponding optimum value of the primary inductance which, for that time, will give the maximum performance. This feature is further considered in Appendix B and may be made to form a useful basis on which to proportion a coil ignition system, the inductance being so chosen that optimum conditions occur with the maximum loading on the system, usually when the mean effective cylinder pressure and secondary voltage required reach their highest values.

It will, however, also be evident that the maximum value of the current factor is under some conditions more a mathematical than a physical fact, as on the one side the curve rises steeply to the maximum point, while on the other it falls off only slowly with further increase in inductance. It is clear that no great harm will result if inductance values in excess of the optimum are chosen, if by so doing some other end is served. If the ignition conditions at high and low speeds require the same secondary voltage, the correct coil inductance will be given by the point of intersection of curve B and the curve appropriate to the Rt value of the coil in question, as such a coil will function equally well at both high and low speeds. Whether low and high speeds require the same voltage depends largely upon what we take as the high-speed limit. In the normal way voltages at starting are higher than at speed, even allowing for the fact that engines are usually started with the throttle nearly closed whereas at high speeds the throttle will be wide open. The reduction in voltage is due to wire-drawing in the valves and induction system and to heating of the plug electrodes. Again, leakage due to moisture on insulating surfaces which may be present at low speeds will be absent when the engine is warm, but on the other hand at high speeds and temperatures leakage may occur through the body of the insulation in the sparking plug, and through carbon deposits which may form upon its surface. The starting conditions we have postulated are extreme ones, as they represent the worst which will occur even under gross abuse of the ignition system, and under such circumstances the user might consider himself lucky to get an occasional or somewhat uncertain spark, which would serve to get the engine started, while under high-speed conditions perfect regularity of sparking is a *sine qua non*. In general it will be found satisfactory if the high-speed conditions be taken as the highest speed at which the engine is expected really to develop power, i.e. as the highest speed the engine is expected to attain when actually driving the car, either under favourable conditions such as on a downward gradient on top gear or on definite upward gradients on the lower gear ratios. For present-day normal engines this high-speed limit is of the order of 4 000 to 4 500 r.p.m.; for racing and supercharged engines, of course, much higher speeds must be catered for.

Returning now to Fig. 6 and considering any given point of intersection between the low-speed curve B and one of the high-speed curves C1, C2, etc., we see that this corresponds to a definite value of L_1 for a given value of Rt and a definite performance factor. It corresponds, therefore, to a definite value of the standstill current I_0, and, since Rt is fixed for a given value of t (the closed period), it corresponds to a definite value of R, and hence of V, the primary voltage. From the series of curves shown in Fig. 6 we can thus derive the curves plotted in Fig. 7, which express the voltage required for coils of different standstill current, each curve of the series being drawn for an appropriate value of t. The chief value of the method of expression adopted in Fig. 7 is that it permits the limits of operation or design to be inserted, so as to indicate not only what current must be taken for ignition systems of different voltages, but also whether or not the coil adopted falls within practicable limits.

PRACTICAL LIMITS IN COIL DESIGN.

The principal limits involved are:—

(*a*) Heating of the coil under standstill conditions.
(*b*) Arcing at the contact points.
(*c*) Limitation of primary inductance.

As regards (*a*), this is, of course, largely a question of the heat-dissipating surface provided and of the heat paths in the coil itself. In cases where a separate resistance is provided it is possible to vary this limit almost at will, but only at the expense of increase in primary copper and hence increase in cost of the coil itself. The heating limit is represented in Fig. 7 by a rectangular hyperbola, and a typical heating-limit curve corresponding to present-day practice for a coil without ballast resistance has been inserted.

The limit (*b*) imposed by arcing, or, as it is somewhat erroneously called, "sparking," at the contact points, is treated more fully in Appendix C. With tungsten contacts, which are invariably used on present-day ignition systems, the limit may be taken as 3·5 amperes at break and as being practically independent of the primary voltage, which is small compared with the voltage at break. Actually, the current broken will slightly exceed the nominal value, as on most cars conditions will occur in daylight running when the charging current from the dynamo at 15 to 20 m.p.h. may cause a rise of battery voltage to about 25 per cent above normal, while the speed will still be low enough to permit the current to attain very nearly its maximum value.

As regards (*c*), in actual practice it is found economically impossible to use primary inductances of higher values than about 50 mH as they could only be obtained either by the use of an inordinately large number of primary (and hence also of secondary) turns, with increase in cost, or by employing a nearly closed iron circuit, with consequent excessive damping and inefficiency.

The above limits have been inserted in Fig. 7, and the resultant will repay a little careful consideration. In the first place, it will be seen that for certain periods of close it is not possible to produce a coil at all without exceeding the limits laid down. For example, with a time of close of 3 milliseconds only one design of coil (which takes 8·5 volts and 3·4 amperes) is possible, and a coil for the usual voltages of 6 or 12 volts cannot be obtained. For still shorter periods of close such as 2·5 or 2 milliseconds, no coil is possible without either the heating or the sparking limit being exceeded, and such a coil can only be produced (to meet the operating conditions postulated) by raising the heating limit, either by adopting a larger coil or by the use of an external resistance. In the second place, it will be evident that from the point of view of efficiency the 12-volt compares badly with the 6-volt system. For example, the 5-millisecond curve corresponds to a voltage of 12 volts with a current of 2·5 amperes, or a standstill power of 30 watts, while at 6 volts the current necessary is only 3·1 amperes, corresponding to 18·6 watts; this again shows the superiority of the low-inductance coil when dealing with a heavily-loaded circuit. On the other hand, for times of close less than 4 milliseconds it is impossible to produce a 6-volt system without exceeding the arcing limit of 3·5 amperes. The curves also indicate that it is undesirable to employ high-inductance coils when low-inductance ones are possible. Consider, for example, the case of a 6-volt, 10-millisecond system which requires a standstill current of 2·5 amperes. It is clear that this could be replaced by a 5-millisecond coil with a contact-breaker cam of appropriate length closing the circuit for half the time, and although the standstill current is slightly greater, viz. 3·1 amperes, the actual current consumptions of the two coils, when running, would clearly be in the ratio 2·5 : 1·55, showing a very pronounced saving in the case of the coil of lower inductance. In contrast with Fig. 7 it is of interest to examine a series of coils based upon open-circuit performance only; such a series is given in Fig. 8, the data being based upon curve B of Fig. 5, i.e. upon a coil designed for optimum ratio at 0·5 MΩ loading but actually operating on no load. It will doubtless be claimed that such an assumption is without justification, and that curve A of Fig. 5 should have been taken in its stead. Against this, however, it must be said that a coil designed in accordance with curve A, i.e. for optimum performance under no-load conditions, would be economically impossible owing to the high winding-ratio and the excessive cost of the secondary, while curve B does actually represent conditions which are economically attainable. The data plotted in Fig. 8 differ from those of Fig. 7 in that in order to provide a margin of performance thay have been worked out for an open-circuit voltage of 10 kV as against the figure of 7·5 kV (with 0·5 MΩ load) used in calculating Fig. 7. It will be seen at once from Fig. 8 that the inferiority of the high-inductance, high-voltage coil practically disappears when open-circuit operation alone is used as a criterion of performance, the various curves approaching much more closely to rectangular hyperbolæ than in the former case. The limiting curve is that for a time of close of 2 milliseconds, which lies closely along the heating-limit line for the whole of its length, giving possible designs between voltages of 16 and 8 volts; at the latter value it intersects the arcing-limit line. For a time of close of 3 milliseconds, 6-volt and 12-volt coils are both equally possible, while for longer periods of close the 12-volt coil requires too high an inductance to be economically sound. The two bases of design exemplified by Figs. 7 and 8 respectively, typify to a certain extent English and American aspects of the ignition problem. In the past, particularly in magneto design, English designers have maintained that the capacity for dealing with a certain amount of leakage (generally known as the "utility" of the system) was essential in any ignition apparatus, and in magneto work a value of 0·25 MΩ at 7 000 to 8 000 volts has been commonly taken as a standard. As will be clear from the foregoing, it is impossible to attain this standard with ignition coils operating on a time of close as low as 3 milliseconds or less, and the question arises whether, with modern engines and sparking plugs, where insulation leakage is probably of less importance than in former times, adherence to this requirement is any longer necessary.

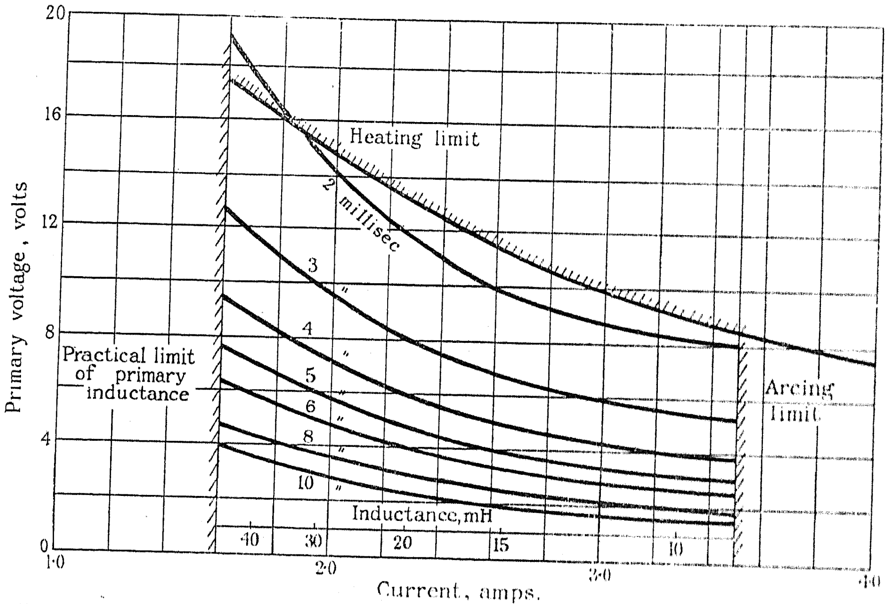

FIG. 8.—Series of coils designed for optimum performance with 0·5-megohm load. Compared under open-circuit conditions at 10 kV.

Possibly the best basis of design is to be found in the adoption of a lower standard of insulation resistance. It may be that a design based purely upon open-circuit voltage will be found to suffice. In any case, the experience which will be gained during the next two or three years in the application of coil systems to British cars should enable a satisfactory criterion to be obtained.

EXTENSION TO ACTUAL COILS.

Although the preceding calculations have served to indicate a number of limiting features in design, they have been based solely upon a hypothetical, perfect coil associated with definite primary and secondary capacitances, without any damping other than that added to it in the form of secondary loading. We must now consider to what extent such a coil agrees with actual practice, and before doing so a few words of description are necessary.

The original coils used for ignition purposes were merely smaller editions of the induction coil developed and employed by physicists for laboratory work, consisting of a soft-iron core constructed either of wire or of strip laminations and wound with the primary winding, surrounded by an external secondary. The primary circuits of such coils generally included an additional "ballast" resistance, the chief object of which was to reduce the amount of heat generated in the primary circuit of the coil if the latter were inadvertently left in circuit. The fact that in such a coil with an internal primary practically the whole of the heat dissipated had to traverse the high-tension winding, and the electrical insulating material associated with it, made the external resistance practically indispensable. In addition, the external or ballast resistance was frequently constructed of nickel, iron or other material with a high temperature-coefficient, with a view to limiting further the current which would flow if the coil were left in circuit with the gine stationary. These coils were naturally circular form and, owing to the fact that the secondary nding was on the outside, were housed in an insu- ing case, the high-tension terminal being usually ated in the centre of the case so as to be as far removed possible from all earthed surfaces.

From time to time various attempts have been made designers to construct such coils with more or less mpletely closed magnetic circuits, somewhat on trans- mer lines, such a construction allowing of sounder chanical construction and easier assembly of the mponent parts. It also held out the possibility of taining high inductances with comparatively few imary turns. Although one can obtain a high induc- ice in this manner, it appears to be impossible to do without increasing the iron losses and the damping such an extent that under no-load conditions, where ternal damping is absent, practically no increase in rrent factor results; the coils of high inductance thus quire practically the same current as those of low, hile, as previously shown, under loaded conditions gh-inductance coils are already at a disadvantage. ie net result, therefore, is that such a closed circuit ves practically no improvement in performance and volves additional charges for iron. The same result n be obtained by using a coil of lower inductance th practically the same current factor, and adjusting e closed period (by varying the cam length) so as to ork on the correct part of the current/time curve.

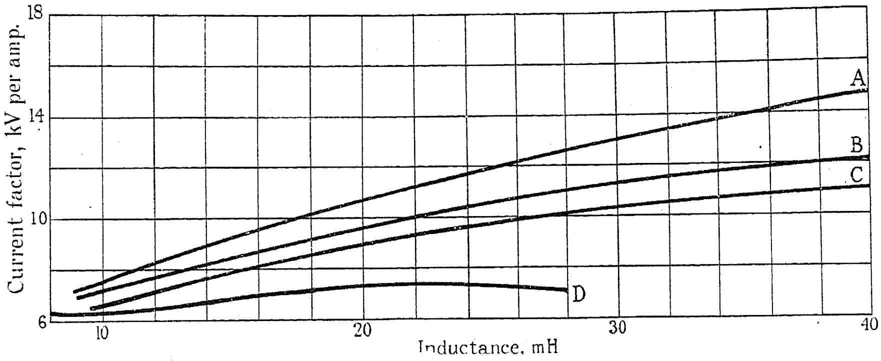

FIG. 9.—Current factors for various coils.

Curve A.—Theoretical curve. No damping
,, B.—Best obtained figures. Alloyed iron core } turns varied.
,, C.—Ordinary figures. Soft-iron core
,, D.—Inductance increased by adding iron to core (turns constant).

During the last few years, however, the so-called external primary" coil has come rapidly to the fore, d has been adopted almost universally in both England d America. The advantages of this type, in which e secondary is wound on and connected to the core, e latter in turn being connected to the high-tension rminal, are:—

(*a*) As the high-tension winding is inside, the mean rn is comparatively short and the weight of wire used less than when this winding is arranged externally. is therefore economically possible to employ a greater mber of secondary turns, and relatively large primary ductances can be obtained in virtue of the turns, ther than in virtue of the linked flux, with a consequent reduction in iron losses and damping, and an improved current factor.

(*b*) As the primary winding is outside, a metal case can be employed and the heat can be readily dissipated. As a result of this, combined with the longer mean turns of the primary and the increased resistance for a given gauge of wire, such coils are usually employed without a ballast or external resistance, that of the coil alone being sufficient. A slight saving in cost is usually possible as a result.

(*c*) The self-capacitance of this type is usually less than that of the older pattern, as the only capacitance involved is that between the core and the primary winding. In the older type of coil, on the other hand, in addition to the self-capacitance of the secondary itself there is a capacitance between its outside layers and surrounding objects.

(*d*) The external primary, with its metal case, lends itself not only to good heat-dissipation but also to a sound mechanical construction, while the high-tension terminal, usually placed in the centre of a moulded end-cap, is also conveniently catered for. The coil possesses no disadvantages to set against these, and as it is felt that this type may be regarded as the standard coil of the future, it will be taken as a basis in the succeeding portions of the paper, unless a distinct statement is made to the contrary.

Reverting to our original argument, we have to inquire to what extent such coils agree in practice with the theoretical coil which has been postulated so far. A method of testing ignition coils, analysing their performance and expressing their characteristics in terms of the fundamental quantities R, L, and C involved is given in Appendix D, but before passing on to this we may usefully refer to Fig. 9, which gives the open-circuit performance factors for various coils as compared with that calculated for a perfect coil free from damping. Curve A in this figure is the same as curve B in Fig. 5, and therefore expresses the performance of a series of coils all designed for optimum conditions. Curve B expresses the results obtained from an actual series of coils in which the ratios were not exactly optimum ones, although they were not greatly removed from them except at the higher-inductance end, where reasons of cost limited the number of secondary turns. Curve C expresses the results for a somewhat similar series of coils in which less attention had been paid to the avoidance of iron losses (Stalloy was used throughout for coils B, ordinary soft iron for C) and the self-capacitance of the secondary was slightly higher. Curve D expresses the results for a series of coils with external secondaries in which the inductance was increased by the addition of iron to the magnetic circuit only. These curves show that the present method of construction leads to a coil the characteristics of which approximate fairly closely to those of the perfect coil. Further, in view of the fact that even with the most careful attention to the magnetic circuit a damping factor D of approximately 90 per cent must be allowed for, corresponding to a reduction of the ordinates of curve A by this amount, it will be seen that reasonably good agreement between theory and practice is attainable. Taking into account the fact that in our present state of knowledge it is impossible to define operating conditions to anything like this degree of accuracy, the position may be regarded as satisfactory. Under loaded conditions, where uncertainty due to damping in the coil itself is a less important factor, still better agreement can be secured.

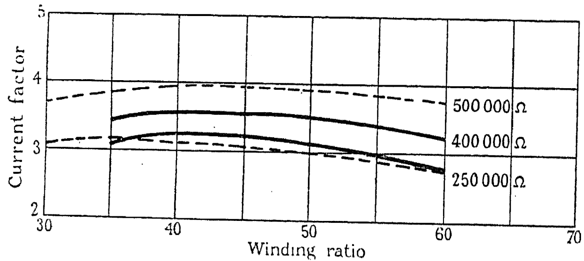

FIG. 10.—Comparison of observed and calculated performances for coils of various ratios. Secondaries loaded as indicated.

- - - - - calculated values.
▬▬▬ observed values.

This is evidenced by Fig. 10, which shows the values of the current factor for various winding ratios calculated from first principles, together with the current factors actually observed on a series of coils made up specially, in which various winding ratios were incorporated.

In view of the above it may justly be claimed that should the problem of designing a coil for given ignition conditions be definable merely in terms of a loaded secondary, in which the loading is of the order of 0·5 megohm or less, so as to mask the damping due to the iron losses themselves, it can be solved purely by calculation and involves no recourse to experimentally obtained data. At present, however, it is by no means certain that such a basis can be regarded as the ultimate one. Apart from the purely technical aspect, it has the disadvantage that the testing of a coil under such conditions is by no means easy, owing to the difficulty of providing a 0·5-MΩ resistor which will carry the load satisfactorily. Further, the buyer of ignition equipment is rarely electrically trained, and a plain test on the basis of open-circuit voltage, or its associated function of spark length, is frequently much more convincing than a partly-understood test involving an added leak. Hence the open-circuit performance of a coil does merit further consideration; such consideration will necessarily involve the question of damping due to iron losses, which has already been briefly touched upon.

The method of testing outlined in Appendix D enables us to obtain the damping factor D by calculation from direct measurement of the first and second voltage-peaks, and also to express the damping either in terms of a single turn of wire linked with the windings of the coil, or, if preferred, in terms of a shunting resistance across the secondary terminals. Neither method of expression is, of course, strictly accurate, as it is impossible to express the effect of magnetic hysteresis or of dielectric loss in terms of a shunting resistance. Even if a resistance were chosen so as to represent these two factors correctly for one particular winding, a different value of the resistance would be necessary if the winding were altered in any way. It appears, however, that for most present-day coils the bulk of the iron losses are due to eddy currents, and it is therefore legitimate to express them by the assumption of a single turn of resistance ρ_0 linked with the windings of the coil. In this case, in place of the term

$$x = \frac{1}{2R}\sqrt{\left(\frac{L_2}{C}\right)}$$

which determines the damping factor, we may write

$$x = \frac{1}{2\rho_0 n_2^2}\sqrt{\left[\frac{n_2^2\lambda}{C_2 + C_1(n_1^2/n_2^2)}\right]}$$

where λ is a function of the magnetic circuit of the coil, such that $L_2 = n_2^2\lambda$.

This reduces to

$$x = \frac{1}{2\rho_0}\sqrt{\left(\frac{\lambda}{n_2^2C_2 + n_1^2C_1}\right)}$$

The relation between D and x is shown in Fig. 11, from which it will be seen that D is an inverse function of x. Consequently, increasing either n_1 or n_2, i.e. increasing either primary or secondary turns, will reduce the damping; while increasing λ, i.e. decreasing the reluctance of the magnetic circuit, will increase the damping. In general, any attempt at constructing a closed-circuit coil will not only involve a relatively large value of λ, but will also, in view of the increased total cross-section of the iron circuit, reduce the value of ρ_0. The fact that curve D in Fig. 9 shows practically no increase in current factor with increase in primary inductance, and that for this coil the higher inductances give evidence of excessive damping, is therefore only what would be expected in view of the above considerations. While adding iron to the magnetic circuit in such a way as to increase the inductance by partly closing the circuit is liable to lead to excessive damping, it is generally possible to add iron to the core so as to increase the area, with beneficial results. Thus Fig. 12 indicates the way in which the value of ρ_0 for a particular series of coils varied when the cross-section of the core was changed, and also indicates the relative damping with different core materials. It will be seen that ρ_0 increases uniformly with increase of section, and that it

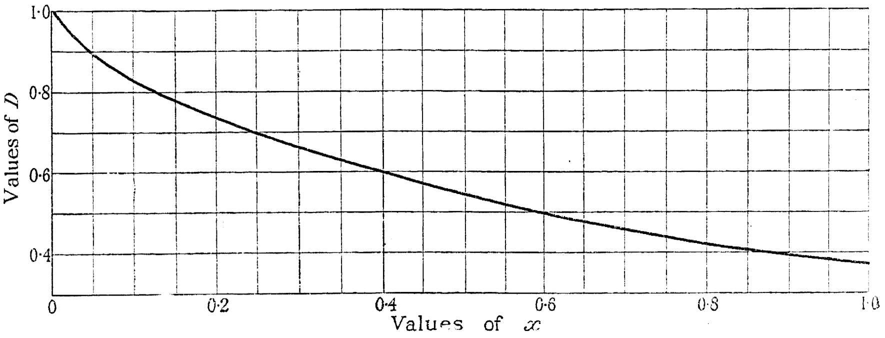

FIG. 11.—Value of damping factor D (= V_1/V_0) in terms of R_2, L_2 and C.

$$x = \frac{1}{2R_2}\sqrt{\left(\frac{L_2}{C}\right)}$$

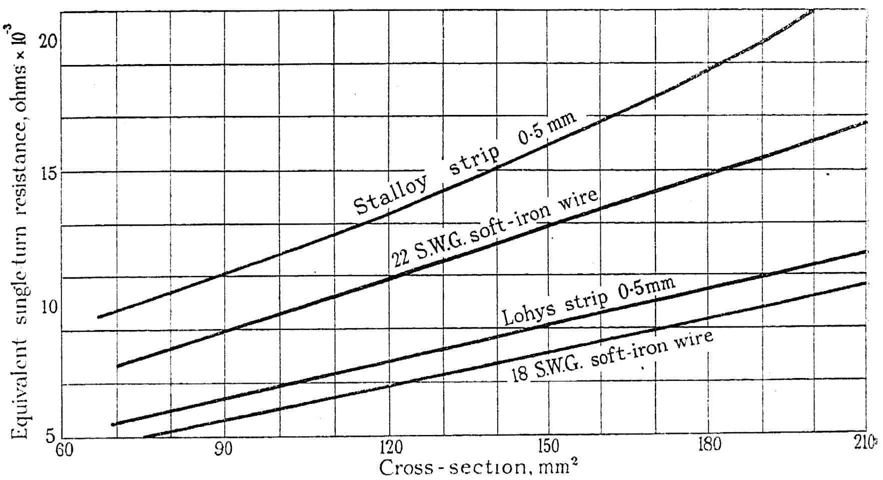

FIG. 12.—Effect of cross-section and material of core on damping of coil.

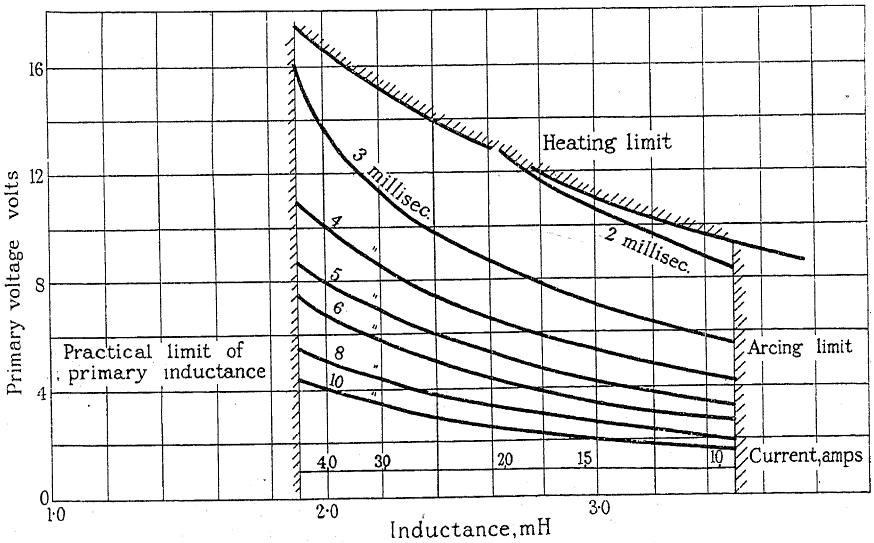

FIG. 13.—Series of coils to give 10 kV on open-circuit. Based on best data from existing designs. Hot starting factor = 0·60. Temperature-rise = 120 deg. C. Watts per degree = 0·18.

is also very largely affected both by the type of material employed and by the degree of lamination of the core. It would appear that with the high frequencies which are involved it might be advisable to adopt an even smaller lamination thickness than the 0·5 mm usually employed. The problem of selecting either the area or the material of the core is primarily an economic one, as increase in area or further subdivision of material naturally involves increased cost. For a given performance it is, of course, possible to pay for such an increase in core cost by a reduction in winding cost, which the increased efficiency of the core would permit. If we consider the expression

$$x = \frac{1}{2\rho_0}\sqrt{\left(\frac{\lambda}{n_2^2 C_2 + n_1^2 C_1}\right)}$$

and imagine ρ_0 changed by increasing either the core area or its degree of lamination, we may obviously—while retaining the same optimum winding-ratio—vary n_2 and n_1 so as to keep both primary inductance and damping unaltered, and hence obtain a coil of the same performance but possibly costing less. It is not proposed in this paper to go into the details of such a calculation, as its results will obviously be of but specialized interest; suffice it to say that the method of attack has been made clear.

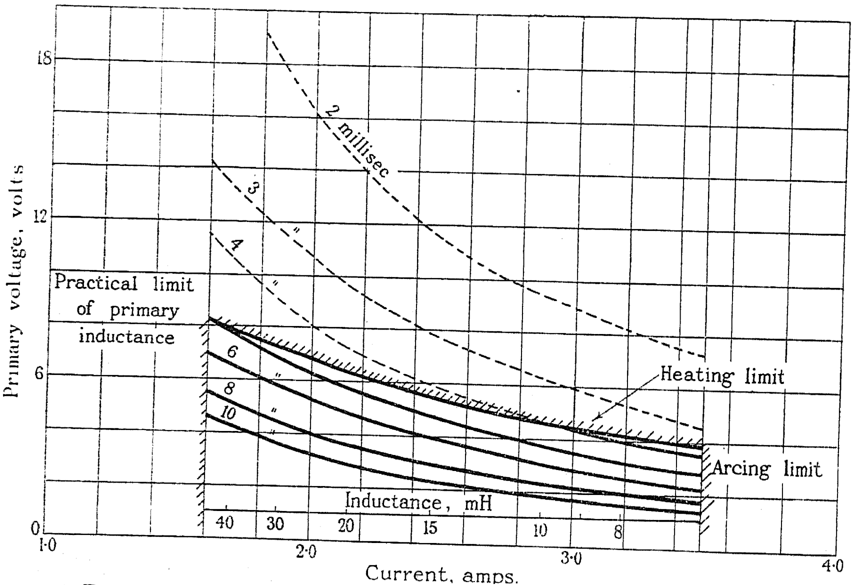

FIG. 14.—Coils as Fig. 13 but for temperature-rise of 60 deg. C.

EFFECT OF VARYING THE BOUNDARY CONDITIONS.

In Figs. 7 and 8 we have seen how the performance of a series of coils may be expressed by a group of curves terminated by definite boundaries representing on the one hand the arcing limit, and on the other the heating limit, while a third slightly less definite limit is set by the highest value of primary inductance which can be obtained without an excessive number of turns and consequent cost. In order to keep our deductions as nearly as possible in line with actual practice, such a series of curves is again plotted in Fig. 13, but taking as a basis the best open-circuit performance (10 kV) obtainable with a series of coils actually manufactured. These curves are not greatly different from those shown in Fig. 8, but they naturally indicate a somewhat poorer performance in view of the increased damping in the actual coils as compared with the ideal ones assumed in the latter figure. For a series of coils under-loaded conditions the theoretically-obtained performances given in Fig. 7 will hold almost exactly. The curves in Fig. 13, which are drawn for a hot starting-factor of 60 per cent with 120 deg. C. temperature-rise, indicate a limiting time of close of 2 milliseconds at 12 volts, the limit lying against the heating boundary, while on a 6-volt system the limit of about 2·8 milliseconds is set by arcing. Fig. 14 shows a similar series of curves based upon the more conservative temperature-rise of 60 deg. C. In this case it will be seen that no 12-volt coil at all is possible, while the 6-volt limit of 5 milliseconds lies on the heating boundary. It can be stated, therefore, that with the present usual type of coil—in which no external resistance is used, all the heat is dissipated from the coil itself, and times of close down to 2·5 or 3 milliseconds are usual—the temperature-rise under "stalled" conditions must reach what is usually considered to be an excessive value. On the other hand, such conditions are exceptional and do not correspond to regular operation. On all English cars, for example, warning devices are fitted the object of which is to prevent the driver from leaving the coil switched on, so that given a careful driver such a condition may never occur during the life of the car.

USE OF ADDITIONAL EXTERNAL RESISTANCE.

The heating-limit boundary can, of course, be raised to any desired extent (apart from mere increase in coil dimensions) by the use of a low-resistance primary combined with a separate resistor, the object of which is merely to get rid of the heat where its presence is least objectionable. This resistor may, if desired, be made of a material which has no temperature coefficient, so as to obviate any reduction in current due to its heating-up, which, in the case of the coil, lowers the hot starting-factor. Usually, however, when a separate resistor is employed its heat capacity is made as small as possible and it can thus respond quickly to any change in the conditions; under these circumstances a positive temperature coefficient can actually confer certain advantages.

Consider for a moment the limiting case, where the resistance of the primary winding is zero and the ballast resistor is working on threshold conditions, i.e. conditions such that a small change in current causes a very large change in resistance. Under these conditions the ballast will act as a current limiter, keeping the R.M.S. current constant over a wide range either of battery voltage or of engine speed. It can be shown that the value of the R.M.S. current in the circuit is given by the expression

$$I_{R.M.S.} = \frac{Vt}{L_1 n^{\frac{1}{2}}} \cdot \frac{1}{a} \sqrt{\left[1 - \frac{(e^{-a} - 3)(e^{-a} - 1)}{2a}\right]}$$

where $a = Rt/L_1$ and n = ratio of total time between sparks to time of close. The expression

$$\frac{1}{a} \sqrt{\left[1 - \frac{(e^{-a} - 3)(e^{-a} - 1)}{2a}\right]}$$

will be found to approach a limiting value of $1/\sqrt{3}$ when $R = 0$, $a = 0$, while, as t increases, the expression for the R.M.S. current approaches the limiting value $V/(Rn^{\frac{1}{2}})$. Hence as the speed of operation is raised, R will decrease, keeping the R.M.S. current constant until $R = 0$, when the current at break will be determined solely by the inductance and time of close. Under these conditions the current at break will clearly be Vt/L_1, and hence equal to $\sqrt{(3n)}$ times the R.M.S. current. With this system, therefore, the current at break will increase to $\sqrt{n}$ times the standstill current as soon as the contact breaker begins to operate, and will rise further to $\sqrt{(3n)}$ when the ballast resistance becomes zero. This is the maximum value attained by the current, which now commences to fall, its value for higher speeds being merely proportional to the time of close. If $I_{max.}$ is the maximum value of the current which can be broken at the contact breaker and if we so arrange matters that this is never exceeded, then the current broken when turning very slowly will be $I_{max.}/\sqrt{(3n)}$, and will, under the conditions we have assumed, be independent of the voltage on the coil. The maximum speed of which the coil is capable may be calculated on the same basis as previously, i.e. on the basis of equality of low and high speed performance. This gives us, for the high-speed limit,

$$\frac{I_{max.}}{\sqrt{(3n)}} = \frac{Vt}{L_1}$$

If we take $I_{max.}$ as 3·5 amperes and choose a value of L to give 7·5 kV with 0·5 MΩ load, we have:—

Current under limiting low or high speed conditions

$$= \frac{3 \cdot 5}{\sqrt{(3n)}} = 1 \cdot 56 \text{ amperes } (n \text{ taken as } 1 \cdot 66)$$

The corresponding inductance is seen from Fig. 5 to be 9 mH, so that $Vt/L_1 = 1 \cdot 56$, and $t = 14 \cdot 1/V$ milliseconds. Hence for a 12-volt system the limiting value of t will be approximately 1·2 milliseconds. This must be compared with the values of 5 milliseconds, given in Fig. 7 under the same conditions for an ordinary coil with heating limitations, and 2 milliseconds, which would hold if the heating limit were removed—either by making the coil much larger, or by fitting it with an additional heat-dissipating resistor made of a material devoid of temperature coefficient.

Theoretically, therefore, the use of a ballast resistor possessing a positive temperature-coefficient enables us to extend the speed range of a coil very considerably and offers possibilities of attacking problems of high-speed operation which could not be dealt with by a plain unballasted coil. Actually, of course, the extension of range which can be obtained is considerably less than that corresponding to the conditions assumed above, as we have assumed the resistance of the coil itself and the cold value of the ballast resistance to be zero. In practice the ratio of the hot to the cold resistance of the ballast is limited by (*a*) the maximum safe temperature at which the ballast resistor can be operated, and (*b*) the temperature at which the self-regulating effect ceases. A simple calculation will show that the condition that a small change in current shall produce a large change in resistance is equivalent to stating that the energy dissipation of the resistor shall be directly proportional to the temperature-rise. This direct proportionality only holds, however, for relatively low temperatures, as above these energy dissipation will follow the usual fourth-power law of radiation. This point is well illustrated by Fig. 15, which gives the I/R relation for a typical ballast resistor. Actually the two factors (*a*) and (*b*) both correspond to approximately the same limiting conditions, a temperature-rise of approximately 500 deg. C., which, with the usual materials employed (nickel or iron), will correspond to a resistance ratio of about 3 : 1.

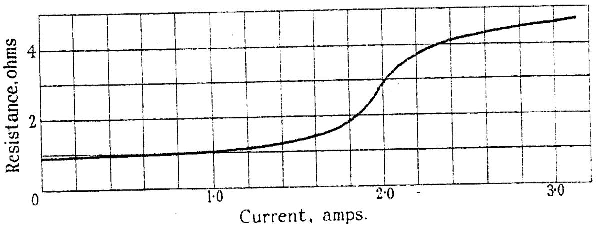

Fig. 15.—Typical current/resistance relation for ballast resistor.

Predetermination of Current in Ballasted-Coil Circuit.

The current flowing in a ballasted-coil circuit at any speed can be determined by equating the R.M.S. current corresponding to a given combination of voltage, resistance, inductance and time of close, to the R.M.S. current which will correspond to the same value of the resistance in the combination of coil and ballast. This can best be done graphically by plotting on the same sheet the two corresponding curves which express the R.M.S. current as a function of the resistance, other factors remaining constant, and taking their point of intersection. By taking further intersection points on a series of curves for different speeds, the relation between resistance of the coil-ballast combination and speed can be determined, and the current at break readily calculated. The method of calculation can best be seen from Fig, 16, in which the curves (1), (2), (3), etc., represent the relation between R.M.S. current and resistance obtained from the equation

$$I_{R.M.S.} = \frac{Vt}{L_1 n^{\frac{1}{2}}} \cdot \frac{1}{a} \sqrt{\left[1 - \frac{(e^{-a} - 3)(e^{-a} - 1)}{2a}\right]}$$

for different values of t, while curve A represents the relation between R.M.S. current and resistance as fixed by the thermal characteristics of coil and ballast. The points of intersection (1)A, (2)A, (3)A, etc., enable the

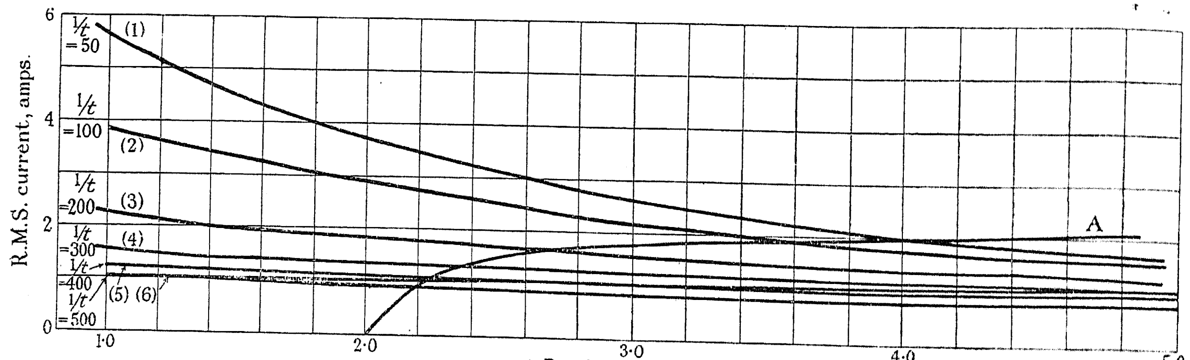

FIG. 16.—Calculation of current at break for coil with ballast resistor. $V = 12$; $L_1 = 10$ mH; 60 per cent close.

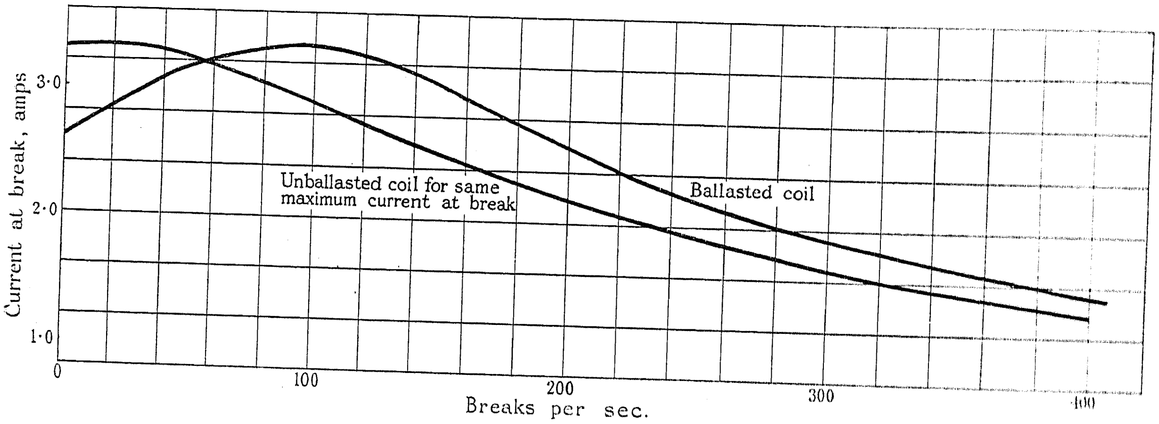

FIG. 17.—Comparison of performance. Coils with and without ballast resistor.

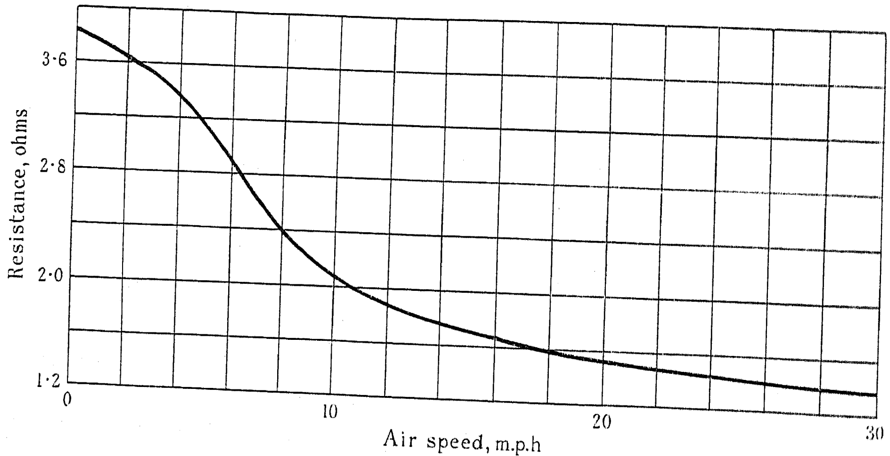

FIG. 18.—Effect of air velocity on resistance of unprotected ballast resistor.

resistance/time characteristic to be plotted, and from this we can obtain the current at break by making use of the usual relation

$$I = I_0(1 - e^{-\alpha})$$

The value of the current at break thus obtained has been plotted in Fig. 17, which, for comparative purposes, also gives the value of the current at break for an unballasted coil. The curve indicates clearly the gain which is rendered possible by the use of a ballast resistor.

Needless to say, as the operation of the ballast resistor depends upon its temperature, it is most important to see that it is so arranged that the heat dissipation follows consistent laws. This means, on a motor-car, that the resistor must be protected from air currents, otherwise it will behave very differently according to whether the car is at rest or on the road. Fig. 18 shows the effect of an air current upon an unshielded ballast resistor and indicates the extent of the possible variation, which, if not taken into account, may cause the current at break, under running conditions, to rise to unsuitable values—sufficient to lead to serious sparking at the contacts.

Methods of Extending Speed Range of Coils.

(1) *By Design of Contact Breaker.*—In the preceding sections we have seen how the range of operating speeds is limited by conditions of heating and sparking, and how it is possible by the use of an external resistor to eliminate the one limit, and by the use of a ballast resistor of high temperature-coefficient to extend the other. The speed of operation can be further extended if means are found to increase the period during which the points are closed, for a given spark-frequency. This period is generally fixed by design of the contact-breaker mechanism, which may be briefly considered at this stage.

The simplest type of contact breaker (see Fig. 19) consists of a light spring-loaded pivoted lever carrying a contact point coacting with a second fixed point mounted in such a manner as to be adjustable for wear. The lever is provided with a pad or heel, usually of fibre or a synthetic resin-bonded fabric, which serves to transmit the motion of the cam and cause the points to separate. The period during which the points are separated may be divided into three portions:—

(i) The period during which the points are moving apart.

(ii) The period during which the crest of the cam passes under the fibre heel, corresponding to a constant separation of the points.

(iii) The period during which the points close again.

Conditions of definite ignition timing and also of arc suppression require that the lever shall be accelerated as rapidly as possible; this requirement is usually met by causing the fibre heel to engage a definitely-inclined cam face, the rate of acceleration being limited only by the elasticity of the arm and pad itself. Having once imparted the necessary velocity to the lever, it has to be brought to rest again by the action of the loading spring, and the cam form should, of course, be such that at no normal speed does the fibre heel leave the cam surface. Since the spring torque and retardation will be sensibly constant (the spring only working through a small angle), these conditions correspond to a parabolic cam form. There is, however, a further requirement, namely, that maladjustment of the contact points shall not cause a serious error in the ignition timing and that frequent readjustment shall not be necessary in service. In order to meet this latter requirement it is usual to adopt a point separation of the order of 0·015 in. (0·375 mm), and, further, in order that an error in point setting shall not cause a serious error in timing, the slope of the cam is usually chosen such that a variation of 0·002 inch in the setting corresponds to an angular error of not more than 1°.

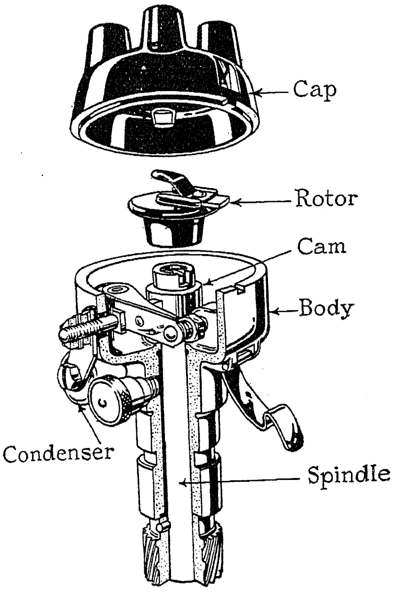

Fig. 19.—Section of typical distributor.

If h is the separation of the contact points (measured in units of 0·001 in.), and θ is the angle turned through in degrees (measured from the crest of the cam), we have

$$h = h_0 - a\theta^2$$

where h_0 is the separation when fully opened and a is a constant. When $h = 0$, i.e. at the point when the heel strikes the cam,

$$h_0 = a\theta_0^2$$

$$\frac{dh_0}{d\theta} = 2a\theta_0$$

Putting $\frac{dh_0}{d\theta} = 2$, gives $a\theta_0 = 1$.

whence $h_0 = \theta_0$

or $\theta_0 = 15°$, for $h_0 = 0·015$ in.

This value of θ_0 is in general greater than is permissible, as it will correspond to a long open period. Further, a purely parabolic cam means that the value of $dh/d\theta$ will not be the same for all adjustments of the points. A better practice is, therefore, to adopt a cam of uniform slope over the usual range of adjustment, blending this into the crest with a parabolic portion. If we arrange for uniform slope from $h = 0\cdot015$ in. to $h = 0\cdot008$ in., we have:—

Angle subtended by straight portion of cam

$$= \tfrac{1}{2}(0\cdot015 - 0\cdot008) \times 1\,000 = 3\cdot5^\circ$$

At the junction of straight flank and parabola, $h = 0\cdot008$ in., and since $dh/d\theta = 2$ we have $\theta_0 = 8^\circ$, giving a total angle of rise of $11\cdot5^\circ$. It will be clear that the closing portion of the cam should in general be a reproduction of the opening portion, the condition that the heel shall not leave the cam being the same in either case. The total period of opening and closing must, therefore, be at least 23°, even if the width of the heel is neglected, while the necessity of providing adequate wearing surface requires that the heel should subtend at least 7·5°, and preferably 10°, giving a total open period of 33°, which, on a 6-cylinder engine, will give a closed period of 27° only, or 45 per cent of the time between sparks.

It will be evident that the closed period can only be increased at the expense of:—

(a) Increased acceleration of lever, entailing increased risk of noise and wear.
(b) Reduced width of fibre heel, with risk of wear and loss of adjustment.

A solution of the problem of increasing the angle of close which has been adopted to a very considerable extent, is that of employing two separate contact-breaker levers disposed at a suitable angle to one another and working on a common cam, the levers being connected in parallel and so arranged that one closes the circuit very shortly after the other has broken it. In this way the open period can be considerably reduced, the only condition being that under extreme cases of bad adjustment the second pair of contacts shall not close before the first pair has opened. With this arrangement an open period of approximately 10° is attainable, and the possible period of close is proportionately increased. This type of contact breaker is generally employed on ignition systems for 8 cylinders and upwards, while it has been used considerably on 6-cylinder units with 6-volt systems in the U.S.A. In this country, where 12-volt systems are the rule for 6-cylinder cars, the need for this type of contact breaker on a 6-cylinder unit does not exist, except in the case of extremely high-speed engines.

(2) *Duplex System.*—A further solution of the problem which is of theoretical interest and has also found practical application is shown in Fig. 20. In this arrangement, which is in certain respects equivalent to a pair of independent systems feeding into a non distributor, two separate low-tension energy-e systems are employed, the energy impulses from are combined and transformed from low to high ial by means of a common transformer.

ore considering this system in detail we may y examine the general question of the separate -storage system upon which it is based, as this somewhat from the ordinary induction coil previously dealt with. The principle of the system is represented in Fig. 21, where L_1 represents a low-tension inductance used as a seat of energy storage, and L_1' represents the primary of a transformer carrying both primary and secondary windings. A contact breaker and battery are arranged as shown in the diagrams, so that when the contact breaker is closed a current flows in the storage inductance L_1. The contact breaker is shunted by a condenser in the usual way. It will be clear that on the opening of the contact breaker the current flowing in L_1 will tend to persist, and hence a current will in general be established in L_1', any change of current in L_1 being manifested by a p.d. across its terminals, with corresponding p.d.'s across both primary and secondary windings of the transformer. If, however, the inductance of L_1' is infinite, clearly no current can be established in it, and under these conditions the only energy transfers which take place will be between L_1 and the condenser. Hence oscillations will occur in this circuit, the current in L_1 alternating in direction and the p.d. on the condenser alternating in sign. The same alternations are impressed upon the transformer, this being in effect shunted across the condenser. The oscillating energy in the circuit will decay as the result of damping in its various parts, or it can be drawn off by loading the secondary of the transformer, and under suitable conditions the whole of the energy originally

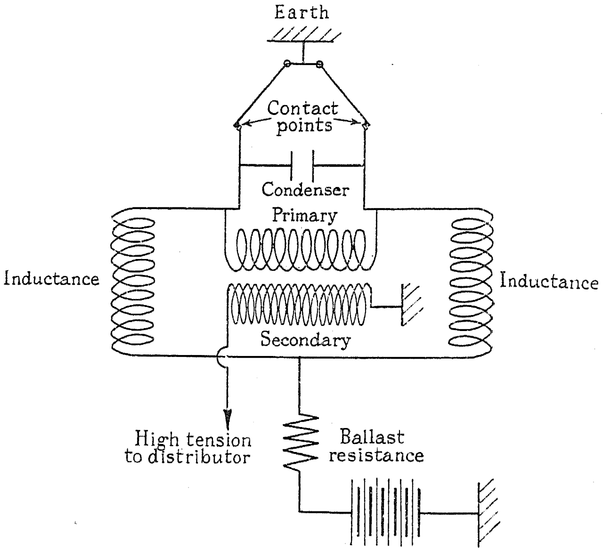

FIG. 20.—Duplex ignition system.

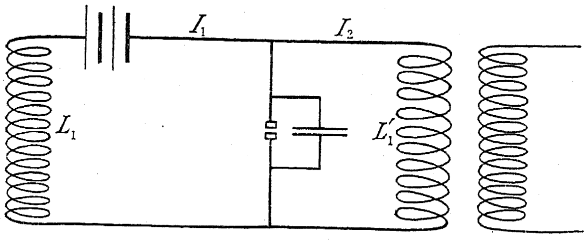

FIG. 21.—Principle of system of separate energy storage.

present in L_1 can be transferred to the secondary circuit. For finite values of L_1' similar conditions hold, with the exception that in this case the whole of the stored energy never appears at one instant in electrostatic form, since under these conditions we have

$$L_1 \frac{dI_1}{dt} = -L_1' \frac{dI_2}{dt}$$

Hence the growth of current in L_1' is (L_1/L_1') times the decay of current in L_1, and when the current in L_1 becomes zero that in L_1' must be finite. In the particular case when $L_1 = L_1'$, the current in L_1, instead of alternating in sign, will oscillate about a mean value $\frac{1}{2}I_1$ between I_1 and 0, while that in L_1' will also oscillate about similar values, I_2 reaching a maximum when $I_1 = 0$, and vice versa. (In the above reasoning the resistance of the system and the e.m.f. of the battery have both been neglected, as these will not affect the initial energy distribution.)

It will be clear that the condition to be aimed at is the maximum possible value of L_1', which naturally leads to a transformer with a closed magnetic circuit as opposed to the usual type of ignition coil. As a result of this and the consequent large amount of iron involved in the whole circuit, the damping of the system is naturally high and its efficiency low, so that up to the present the arrangement has found only very limited application. It has, however, been used fairly extensively in various types of magnetos, the winding L_1 in this case forming the winding of a low-tension armature and the battery being omitted; it has also been employed for certain dual ignition systems, in which case the magneto armature takes the place of the transformer, energy supplied by a battery being stored in a separate low-tension inductance. The particular arrangement shown in Fig. 20 is of interest in that a single condenser and transformer serve the two storage inductances in turn, and that the current in the transformer alternates in direction, the impulses being alternately positive and negative, instead of all being of the same sign as in an ordinary coil. In the arrangement shown the two contact breakers are operated alternately, care being taken to arrange the cams so that they are never both open together. On the closing of a contact breaker the current in the corresponding inductance commences to rise, and when it is ruptured the energy is transferred via the second pair of contact points to the transformer circuit. As spark impulses are drawn alternately from the two systems the time available for the storage of energy is twice the interval between sparks, thus permitting of a considerably extended speed range as compared with that of an ordinary coil set. On the other hand, the low efficiency due to the large amount of iron involved in the circuit does not allow the whole of the possible extension of range to be realized. A further possible advantage is that the use of a closed-core transformer, with consequent good coupling, may increase the life of the contact-breaker points by reducing the amount of energy linked with the primary only, which, under certain conditions, must be dissipated in the primary circuit.

(3) *Condenser and Transformer Systems.*—A system which is at present only of theoretical interest, and which, strictly speaking, should not be classed as a coil system at all, has been described by the author and has later been suggested by Dr. F. W. Lanchester. It consists merely of a condenser charged to an appropriate voltage, conveniently about 200 volts, and connected periodically by means of a contact maker to the primary of a step-up transformer, which takes the place of a coil. If the coupling of the transformer windings is perfect the spark takes place immediately the primary circuit is closed, and as the rise of voltage is instantaneous, secondary loading has no effect upon the performance, an infinite "utility" being theoretically available. Actually, "utility" values many times higher than that possible with a normal ignition system can be readily attained. The apparatus is very simple, but the difficulty in automobile practice is the provision of the necessary high voltage of 200 volts or thereabouts. Lower voltages are unsatisfactory, as they necessitate very large energy-storage condensers and the current to be handled by the contact maker is excessive. The difficulty of the provision of the high voltage really rules out this system in most cases, but it may occasionally find application under special conditions.

CONSTRUCTIONAL DETAILS.

The mechanical design of distributors and coils is now standardized to a very large extent, and there is little difference between the products of different makers. The contact breaker and distributor (for multi-cylinder engines) are practically always combined in a common unit, generally termed the "distributor head" or the "distributor." Those dimensions which affect interchangeability of this unit as a whole have been standardized, the same standards being worked to in both this country and the U.S.A.

The distributor (see Fig. 19) combines the following component parts:—

(*a*) Body and bearing.
(*b*) Spindle and cam.
(*c*) Contact-breaker assembly.
(*d*) Condenser.
(*e*) Distributor rotor.
(*f*) Distributor cap.

(*a*) *Body and Bearing.*—The body is in practically all cases an iron casting, and cast iron is also frequently used for the bearing itself. Provided good-quality material is used and the bearing surfaces are well finished perfectly satisfactory results are obtained, although inserted bronze bushes are in one or two instances used as an additional precaution. The bearing, if of cast iron, is frequently finished by broaching, which enables a better-finished surface to be obtained than is possible with a drilling and reaming operation.

(*b*) *Spindle and Cam.*—Distributors with manual advance only usually have the spindle and cam in one piece, although one of the largest makers of cars at the present time uses a construction in which the cam is separate from the spindle. The advantage of the separate cam is that the cam only need be heat-treated and the spindle may be of mild steel, whereas with the one-piece construction both spindle and cam must be heat-treated together, as a thoroughly hard cam is found to be essential to prevent wear of the fibre heel. The disadvantage of the two-piece construction is, of course, the necessity for extreme accuracy in view of the fact that a small eccentricity of the cam on a multi-cylinder engine will cause a corresponding variation in the firing points of the various cylinders. For example, taking a cam form giving a variation of 1° for every 0·002 in. at the contact points, and assuming a lever ratio [i.e. (radius to contact point)/(radius to fibre heel)] of 2 : 1, we see that an eccentricity of 0·001 in. will cause one cam to open the points 0·004 in. more than the opposite one, and will therefore give a timing variation of 2°.

In the so-called "automatic" distributor, where an automatic advance mechanism is disposed between the driving spindle and the cam, the latter is naturally a separate member, but must in this case also be accurately centered with respect to the spindle. Up to the present case-hardened cams have been universally employed, but the new nitriding steels would appear to offer possibilities of distinct improvements, not only in view of the increased hardness of the surface but also as a result of the fact that the nitrided skin is to a very large extent corrosion- and rust-resistant. This property is particularly valuable in connection with equipment exported overseas and liable to rusting in transit, as a cam which is initially rusty and rough will, when put into service, give rise to rapid wear of the fibre heel.

(*c*) *Contact-Breaker Assembly.*—At the present time a pressed-steel contact-breaker lever is practically universal, the lever consisting of a light pressing, suitably channelled for strength and rigidity, to which is attached the fibre heel and contact point. The bearing bush usually consists of synthetic-resin bonded paper, although brass is still occasionally employed. The former material is preferable as it requires less lubrication and allows more flexibility in design, since it permits the use of a live lever in conjunction with an earthed pivot-pin, if this is desired. The contact point, which at the present time is practically always of tungsten, is welded either directly on to one end of the lever, or else on to a separate shank, which is subsequently fixed by spinning or riveting. The former method of attachment reduces the mass to some extent owing to the absence of the shank, but the lever itself must in this case be formed of a low-carbon steel having a low elastic limit and tensile strength; with a separately-assembled contact, on the other hand, a heat-treated lever may be employed and the strength correspondingly increased, or the weight of the lever itself may be reduced. The actuating spring is generally of flat strip, and high-carbon steel strip of similar composition to that used for clock springs is generally employed. In some cases the material is merely hardened by cold working, in others the spring is hardened and tempered in the usual way. The two methods appear to give equally good results, and trouble due to broken springs is of very rare occurrence. Torsion springs of piano wire are also employed, but if this is done it is usual, owing to the inductance of the coiled spring and the necessity of avoiding all possible inductance in the condenser circuit, to arrange a small auxiliary spring or strip of phosphor bronze to carry the current to the contacts. In the majority of designs, typical examples of which are shown in Figs. 22A and 22B, the contact point is attached to the same side of the lever as the fibre heel, the ratio of the radii to point and heel respectively being approximately 2 : 1. The alternative construction which makes use of a bell crank lever is also occasionally employed and would appear to merit more general adoption. The chief points in its favour are:—

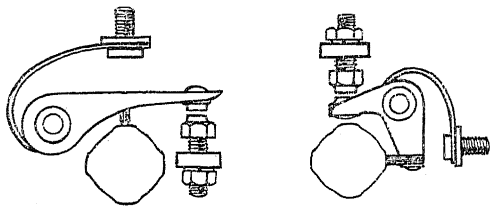

FIG. 22A.—Alternative contact-breaker lever arrangements.

(i) A 1 : 1 ratio between heel and point can be obtained, which means that less accuracy is necessary in the forming and centering of the cam and that for the same contact pressure the pressure and wear on the heel is less.

(ii) The contact points are less liable to receive any oil and dirt which works up the spindle and is thrown off by the cam.

(iii) Owing to the reduced mass and greater rigidity of the bell crank lever, quieter operation at high speeds is possible.

The adjustable contact point is usually mounted on the end of a screw locked in position either by a lock-nut or by the use of a clamping screw in conjunction with a split block into which the screw is tapped. An alternative arrangement which is gaining favour is to carry the adjustable point on a bracket, usually pivoted round the centre of rotation of the contact-breaker lever, and locked in position by a screw passing through an elongated hole. The chief advantage of this arrangement, apart from possible cheapness in manufacture, is that the "bedding" of the contact points is not disturbed when adjustment is made, whereas with the screw adjustment the rotation of the screw naturally destroys all bedding which may have existed initially.

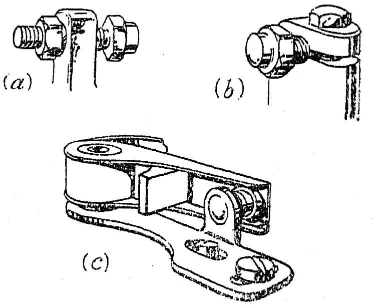

FIG. 22B.—Alternative methods of providing adjustment.

(*a*) Screw and lock-nut.
(*b*) Screw and split block.
(*c*) Eccentric screw.

(*d*) *Condenser.*—On practically all present-day designs a rolled-paper condenser is employed. The condenser is manufactured by rolling up strips of 2-ply or 3-ply paper tissue sandwiched between two strips of tinfoil, which overhang on opposite sides. The result is a tubular condenser with the terminals at opposite ends, current being fed into the strip along the whole of its length from the edge. This results in a condenser of very low internal resistance, a most important point in a condenser used for spark suppression. The completed condenser is vacuum-dried, impregnated with a suitable wax and sealed into a metal case. At one time paraffin wax was employed for insulation, but more recently a chloronapthalene substitution product known as "Halowax" has been largely adopted. The chief merit of this material is that its very much higher dielectric constant (4 as against 2·3 for paraffin wax) leads to a considerable saving in bulk and cost for a given capacitance. The substance also has a slight advantage in that its melting point is somewhat higher than that of paraffin. In practically all modern designs the condenser is mounted inside the distributor, as close as possible to the contact points, so as to reduce to a minimum the resistance and inductance of the condenser circuit. The old practice of combining the condenser with the coil has now been practically abandoned, and while in occasional instances the condenser is mounted on the outside of the distributor and connected to it by a strap, this practice is gradually being abandoned, largely perhaps as the result of the neater appearance of the alternative design.

(*e*) and (*f*).—*Distributor Rotor and Distributor Cap.*—These parts can best be dealt with together, as they form the high-tension distribution system. On the end of the spindle is carried the distributor rotor, a small moulding to which is attached an insulated metal segment serving to distribute the current to the various electrodes carried in the distributor cap, which encloses the contact breaker. The rotor is fed from a central terminal in the cap, to which the high-tension lead from the coil is connected. The so-called "jump spark" method of distribution is practically universal, the rotor segment revolving close to, but not quite touching, the distributor segments. The chief merits of this system are cheapness, simplicity and absence of trouble due to carbon dust. The chief disadvantage is the necessity for ventilation, in the absence of which the oxides of nitrogen produced cause serious corrosion of all steel parts, and there is a possibility of oil mist and dirt being drawn in from outside, through the ventilating holes. There is also a potential risk of fire unless wire gauze is fitted over the openings, but on the other hand wire gauze is generally unsatisfactory as it soon chokes with oil and dirt. Probably both systems of distribution have their fields of usefulness under different operating conditions. Manual control of the ignition point is in the majority of cases effected by rotating the distributor bodily, but in the Ford car the contact breaker only is rotated, the distributor itself remaining fixed. The object of this is to enable rigid connections to be used between the distributor terminals and the engine cylinders, the chief disadvantage being that the position of the rotor relative to the distributor segments does not remain constant and a wider rotor is necessary than when the distributor is rotated as a whole. For relatively small angular movements this objection is not, however, a serious one, at all events on 4-cylinder engines.

Automatic advance mechanisms can hardly be dealt with adequately unless a paper is devoted to them alone. Their function is to advance the point of ignition as the engine speed increases. The correct point of ignition is for a given engine a function first of engine speed and secondly of inlet-pipe depression, increased advance being required as the speed rises and also as the vacuum in the inlet manifold increases. Numerous types of centrifugal mechanisms have been developed to advance the ignition as the speed increases, while the second factor has been introduced by the use of a vacuum-operated piston which rotates the distributor itself. A recent suggestion is to introduce this factor by means of appropriate linkage connected to the acceleration pedal, so arranged as to give maximum advance when the throttle is closed. The provision of a satisfactory centrifugal mechanism is by no means easy, owing to the wide range of forces acting. For example, if the mechanism is to commence to advance at 500 r.p.m. and complete its advance at 3 000 r.p.m., the range of operating force will be at least 36 : 1, and actually considerably more than this, owing to the increase in effective radius of the centre of gravity of the rotating masses with the speed. This means that unless large masses are used the forces acting and the control at low speeds will be weak; the mechanism will therefore tend to rattle and will be affected by the frictional forces between the contact-breaker lever and the cam. As any form of directly spring-loaded mechanism will give a concave curve, i.e. $d^2\theta/dn^2$ positive (θ being the angle of advance and n the speed), and as convex curves—or at any rate linear relations—are required by practically all engine designs, it is necessary to employ some method of connection between the control spring and the centrifugal masses which increases the moment of the spring as the masses move outwards. Many ingenious mechanisms have been developed with this end in view.

COIL CONSTRUCTION.

The almost universal adoption of the external-primary type of coil has given rise to what is practically a standard construction. The core is usually composed of laminated strip, as this involves a smaller assembly cost than wire. The secondary winding is wound either on the core itself or on an insulating tube into which the core is subsequently inserted, while the primary winding is either wound directly on top of the secondary or on a separate insulating tube which is fitted to the secondary at a later stage. Round the primary is placed an iron sheath, usually slotted and laminated, to prevent eddy-current losses, which serves the twofold purpose of increasing the coil inductance and preventing losses due to the flux linking with the unlaminated sheet-iron container. The whole coil assembly is fitted into this container and sealed with pitch. For reasons of heat dissipation the primary winding and its sheath should naturally fit the container as closely as possible, consistent with adequate insulation. The lower end of the container is closed by a metal cap, and the upper end by a synthetic-resin moulding which carries the low-tension and high-tension terminals. Insulation of the windings is usually affected by means of wax-impregnated paper, the coil being impregnated with wax or a resin-wax mixture after winding, but in certain cases varnished paper and cloth, as used in magneto practice, are employed. The former has the advantage of giving a slightly lower self-capacitance, and, if due precautions are taken against escape of wax when the coil is hot, it appears to give satisfactory results in service.

Conclusion.

The aim of the paper has been to point out the basic principles underlying the application of a perfectly well-known and, in general, thoroughly well worked-out piece of apparatus—the induction coil—to a specific purpose, and to indicate the limits which are met with in its application and how they may be controlled. At the present time the situation may be said to be well in hand, in that no difficulty is encountered in meeting the conditions laid down by the user of the apparatus.

The present problems of the manufacturer are primarily detail ones covering small points conducive to cheapness in manufacture and reliability in operation, and it does not appear that any radical change in design is likely to occur in, at all events, the near future. At the same time, as indicated in the paper, should conditions of working become more onerous, modified systems exist which can doubtless be developed to meet any possible requirements. Perhaps the biggest outcome which can be hoped for from this paper is that, as a result of the applications of the principles laid down, it may be possible to arrive at a better utilization of material in existing types of coils, with a saving in production costs.

In conclusion, the author would express his indebtedness to Mr. J. A. Laird, who was responsible for much of the experimental technique of the work, and in particular for the ingenious method of determining coil performance which is described in Appendix D. Thanks are also due to Mr. E. J. Youel, who carried out a number of the tests the results of which are embodied in the various curves reproduced, and to various other members of the author's staff who contributed to the work. Acknowledgments to the author's firm, in whose laboratories the investigation was carried out, must, as a result of the change in ownership, be made to their successors, Messrs. Joseph Lucas, Ltd.

APPENDIX A.

E.M.F. Wave-Form Produced when a Current is Broken in an Inductive Circuit Shunted by a Resistance.

The growth of e.m.f. in the circuit is, as shown in the paper, given by the differential equation

$$C\frac{d^2V}{dt^2} + \frac{1}{R_2}\cdot\frac{dV}{dt} + \frac{V}{L_2} = 0$$

Provided R is less than $\sqrt{(L_2/4C)}$, the e.m.f. takes the form of a damped sine-wave whose equation is

$$V = e^{-\mu t}K \sin \sqrt{(n^2 - \mu^2)}t$$

where $n^2 = 1/L_2C$, $\mu = 1/2R_2C$ and K is a constant of integration. K can be shown to be equal to $V_0n/\sqrt{(n^2 - \mu^2)}$, where V_0 is the amplitude of the voltage wave in the absence of all damping. The expression for the secondary e.m.f. is therefore

$$V = \frac{n}{\sqrt{(n^2 - \mu^2)}}e^{-\mu t}V_0 \sin \sqrt{(n^2 - \mu^2)}t \quad . \quad . \quad (1)$$

It will be seen from the form of the expression that the periodic time of the voltage-wave increases with the damping, becoming infinite when $n = \mu$, i.e. when $R_2 = \sqrt{(L_2/4C)}$. On the other hand, the time to the first voltage peak decreases slightly as the damping increases. The first peak occurs when $dV/dt = 0$, i.e. when

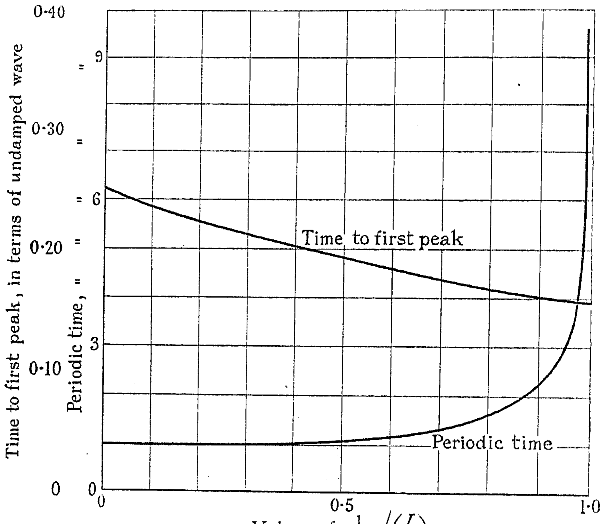

Fig. 23.—Effect of damping on periodic time.

$$\sqrt{(n^2 - \mu^2)} \cos \sqrt{(n^2 - \mu^2)}t = \mu \sin \sqrt{(n^2 - \mu^2)}t$$
$$\tan \theta = \sqrt{(n^2 - \mu^2)}/\mu, \text{ where } \theta = \sqrt{(n^2 - \mu^2)}t$$
$$\cos \theta = \mu/n$$

When no damping exists θ is, of course, equal to $\frac{1}{2}\pi$, while for critical damping $\cos \theta = 1$, or $\theta = 0$. On the other hand, since the actual time to the first peak is equal to $\theta/\sqrt{(n^2 - \mu^2)}$, we have $t = \frac{1}{2}\pi\sqrt{(L_2C)}$ for zero damping. For critical damping, t is the limiting value of $\theta/\sqrt{(n^2 - \mu^2)}$ when both numerator and denominator become zero, and is equal to L_2C, i.e. $2/\pi$ of the value when the damping is zero.

Fig. 23 shows graphically the way in which the time to the first peak and the wavelength vary as the damping is increased up to the critical value, while Fig. 24 gives a series of wave-forms for different values of damping and the same value of V_0. It will be noticed from these that the increase in wavelength predicted by theory has no practical significance, as for these cases, where the wavelength is appreciably increased, the damping is so heavy that the second and subsequent peaks are virtually non-existent. Confirmation of this is given by Fig. 25, which shows the secondary oscillograms taken on an ordinary ignition coil both unloaded, and with various loads connected to the secondary terminals. The difference between the damping in the unloaded and loaded conditions is well marked.

If we write

$$x = \frac{1}{2R_2}\sqrt{\frac{L_2}{C}}$$

the equation takes the simpler form

$$V_1 = V_0 e^{-\frac{x}{\sqrt{(1-x^2)}} \text{arc cos } x} \quad . \quad . \quad . \quad . \quad (4)$$

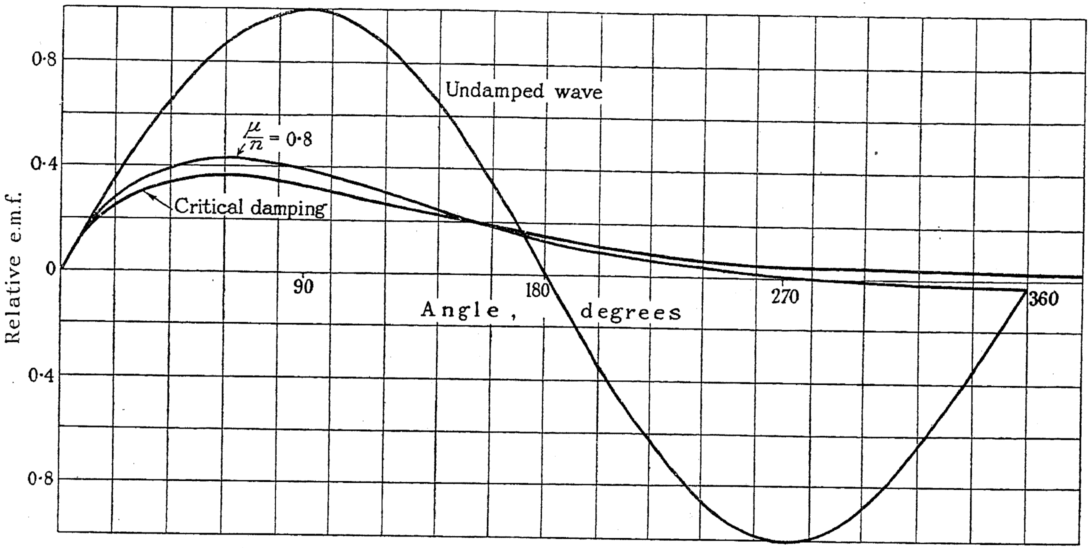

FIG. 24.—Undamped, partially, and critically damped waves.

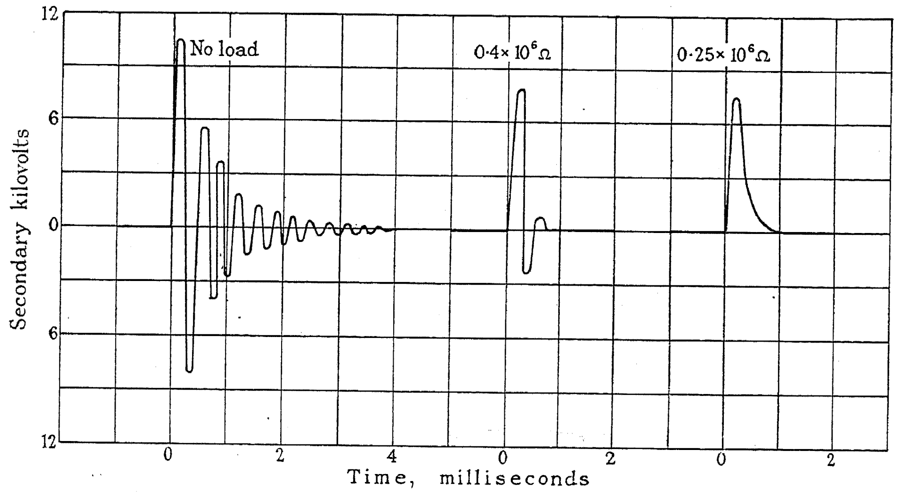

FIG. 25.—Cathode-ray oscillograms for loaded and unloaded secondary.

Value of First Voltage-Peak.—Inserting the value of t at the first peak in equation (1), we obtain:—

Voltage at first peak $= V_1 = V_0 e^{-\mu t_1}$

where
$$t_1 = \frac{\text{arc cos } (\mu/n)}{\sqrt{(n^2 - \mu^2)}}$$

or
$$V_1 = V_0 e^{-\frac{\mu}{\sqrt{(n^2-\mu^2)}} \text{arc cos } (\mu/n)} \quad . \quad . \quad . \quad (2)$$

Inserting the values of μ and n gives

$$V_1 = V_0 e^{-\sqrt{\left[\frac{L_2}{C}\left(\frac{1}{4R_2^2 - L_2/C}\right)\right]} \text{arc cos} \left[\frac{1}{2R_2}\sqrt{\frac{L_2}{C}}\right]} \quad . \quad (3)$$

APPENDIX B.

CHOICE OF INDUCTANCE FOR OPTIMUM VALUE OF STORED ENERGY.

The inductance of an iron-cored circuit is in general somewhat difficult to define, as different values will be obtained according to the definition which is adopted.

The following definitions may be employed:—

(*a*) $$L = n\frac{d\Phi}{dI}$$

where n is the number of turns, Φ the flux, and I the current. This is the usual definition corresponding to

$$V = L\frac{dI}{dt}$$

(b) $$L = \frac{n\Phi}{I}$$

i.e. the total flux-turns divided by the current flowing.

(c) $$L = \frac{2E}{I^2}$$

where L is defined in terms of the energy (E) stored for a given current.

Fortunately, however, in all ignition coils the reluctance of the iron portion is negligible, so that the same value of L is obtained whichever definition is employed.

From the usual formulæ for the rise of current in an inductive circuit we have

$$\begin{aligned} E &= \tfrac{1}{2}LI^2 = \tfrac{1}{2}LI_0^2(1 - e^{-Rt/L})^2 \\ &= \tfrac{1}{2}LI_0^2[1 - 2e^{-Rt/L} + e^{-2Rt/L}] \quad . \ . \ . \quad (1) \end{aligned}$$

Differentiating (1) with respect to L and equating to zero gives, after simplification:—

$$(1 - e^{-Rt/L})\left[1 - \left(\frac{2Rt}{L} + 1\right)e^{-Rt/L}\right] = 0$$

The solution, $1 - e^{-Rt/L} = 0$, corresponds to the condition when $L = \infty$, i.e. to the condition of minimum energy-storage. The alternative solution is given by

$$\left(\frac{2Rt}{L} + 1\right)e^{-Rt/L} = 1$$

$$e^{-Rt/L} = \frac{L}{L + 2Rt}$$

$$-\frac{Rt}{L} = \log_e \frac{1}{1 + 2Rt/L} \quad . \ . \ . \ . \quad (2)$$

An approximate solution of (2) is

$$Rt/L = 1{\cdot}256 \quad . \ . \ . \ . \ . \quad (3)$$

This enables us to proportion the inductances so as to provide the maximum possible storage energy for a given coil resistance and battery voltage at any given engine speed. For the case when $Rt/L = 1{\cdot}256$ we have the following relations:—

(a) *Current at Break.*

$$\begin{aligned} I &= I_0(1 - e^{-1\cdot256}) \\ &= I_0(1 - 0{\cdot}286) \\ &= 0{\cdot}714I_0 \quad . \ . \ . \ . \ . \ . \ . \ . \quad (4) \end{aligned}$$

(b) *Stored Energy.*

$$E = \tfrac{1}{2}LI^2 = 0{\cdot}202Rt_{min.}I_0^2 = 0{\cdot}202VI_0t_{min.} \quad . \ . \ . \quad (5)$$

Hence

$$\begin{aligned} t_{min.} &= \frac{E}{0{\cdot}202RI_0^2} \\ &= 5 \times \frac{\text{Energy}}{\text{Stationary consumption}} \text{ (approx.)} \quad . \quad (6) \end{aligned}$$

This is an approximate expression for $t_{min.}$, the optimum time, in terms of the energy and the stationary current consumption.

(c) *Energy Drawn from Battery in Establishing Field.*

This is equal to

$$\begin{aligned} \int_0^{t_{min.}} VIdt &= VI_0\int_0^{t_{min.}} (1 - e^{-Rt/L})dt \\ &= VI_0\left[t_{min.} + \frac{L}{R}(e^{-Rt_{min.}/L} - e^0)\right] \\ &= VI_0\left[t_{min.} - \frac{L}{R}(1 - e^{-Rt_{min.}/L})\right] \\ &= VI_0t_{min.}[1 - 0{\cdot}796(1 - 0{\cdot}286)] \\ &= VI_0t_{min.}(1 - 0{\cdot}569) \\ &= 0{\cdot}431VI_0t_{min.} \quad . \ . \ . \ . \ . \ . \ . \ . \ . \quad (7) \end{aligned}$$

(d) *Efficiency, or Ratio of Energy Stored to Energy Drawn from Battery.*

This is equal to

$$\frac{0{\cdot}202VI_0t_{min.}}{0{\cdot}431VI_0t_{min.}} = 0{\cdot}468 \quad . \ . \ . \ . \ . \quad (8)$$

Determination of Coil Coefficients for Given Performance.

In general the value of $t_{min.}$ is fixed by the engine speed, number of cylinders, and angle of make of the contact breaker, so that on the assumption of a given value of E, the necessary stored energy, we are able to determine the coil coefficients as follows:—

$$\begin{aligned} I_0 = \text{“ stalled ” or stationary current} &= \frac{E}{0{\cdot}202Vt_{min.}} \\ &= \frac{5E}{Vt_{min.}} \text{ (approx.)} \quad . \quad (9) \end{aligned}$$

$$W_0 = \text{“stalled ” power consumption} = \frac{5E}{t_{min.}} \quad . \ . \quad (10)$$

$$\begin{aligned} L = \text{inductance} &= 0{\cdot}796Rt_{min.} = 0{\cdot}796Vt_{min.}/I_0 \\ &= \frac{0{\cdot}796Vt_{min.}}{E/(0{\cdot}202Vt_{min.})} = \frac{0{\cdot}161(Vt_{min.})^2}{E} \quad . \quad (11) \end{aligned}$$

(e) *Primary Flux Linkage* (λ).

This is equal to $L \times I$ and has the following values:—

Under “ stalled ” conditions, $\lambda_0 = LI_0 = 0{\cdot}796Vt_{min.}$ (12)

Under optimum conditions, $\lambda_{min.} = LI_{min.} = 0{\cdot}569Vt_{min.}$ (13)

These relations enable us to determine the core size for any given primary winding, since λ is also equal to the product of flux and turns. As indicated in the body of the paper, however, this method of design—although of some theoretical interest—is not of much value owing to the very flat maximum given by the energy curve, and also to the fact that if the coil is designed on the basis of optimum inductance it is liable to give bad starting with a low battery-voltage when I is less than $0{\cdot}714\ I_0$ and the energy is, therefore, less than that postulated.

APPENDIX C.

ARCING AND SPARKING AT CONTACT-BREAKER POINTS.

The underlying principles of the so-called " sparkless " interruption of current in an inductive circuit with the break shunted by a condenser have been given by the author in a previous paper.* In that paper, use was made of the so-called " minimal arc " characteristic of the contact-point materials and it was shown that the arc was either extinguished within a fraction of a microsecond (so-called " sparkless " break), or, if the conditions were adverse, a persistent arc formed, which might last a few milliseconds. In the latter case " sparking " is usually said to occur.

The question whether interruption shall be " sparkless " or not, depends upon:—

(*a*) The current broken.
(*b*) The material of the contacts.
(*c*) The capacitance of the condenser employed.
(*d*) The resistance, and particularly the inductance, in the condenser leads.

Provided the final p.d. across the contacts does not exceed about 250 volts, the conditions at break are almost independent of the voltage, and are a function of the above four quantities only. Fig. 26 expresses the relation between ultimate contact-breaker voltage (i.e. voltage finally attained after separation) and current broken for tungsten contacts, and various values of the condenser capacitance, the condenser in each case being placed as near to the points as possible. From this curve it will be noted that:—

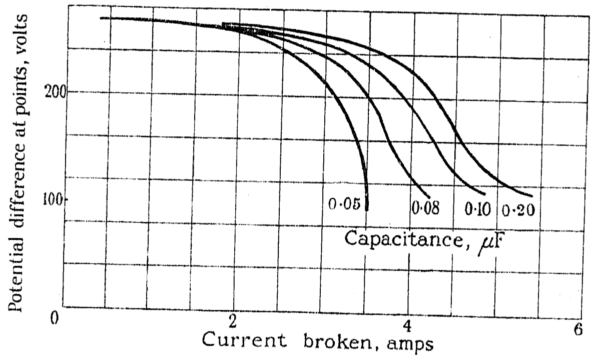

FIG. 26.—Rupturing capacity of tungsten points. Discs, 4·75 mm diameter.

(i) For voltages below 270 volts the current which can be broken is a function of the condenser capacitance.
(ii) Increase in capacitance beyond 0·10 μF gives little further gain in breaking power.
(iii) If the voltage exceeds 270 volts a sparkless break is impossible, no matter what the capacitance or the current.

The explanation of the last fact is that above 270 volts true sparking due to gaseous ionization occurs, while below this voltage the so-called " spark " is really an arc, i.e. the current is carried by metallic ions liberated from the contact faces themselves. In confirmation of this it is of interest to note that in a comprehensive series of tests under different conditions and with different materials the same upper limit of voltage of 270 to 280 volts was obtained throughout.

APPENDIX D.

ANALYSIS OF COIL PERFORMANCE.

As indicated in the paper, the performance of a coil can be completely predicted if we are able to measure the following quantities:

(*a*) Primary inductance.
(*b*) Equivalent self-capacitance expressed in terms of secondary.
(*c*) Damping factor, i.e. damping due to losses—both magnetic and dielectric—in the coil.

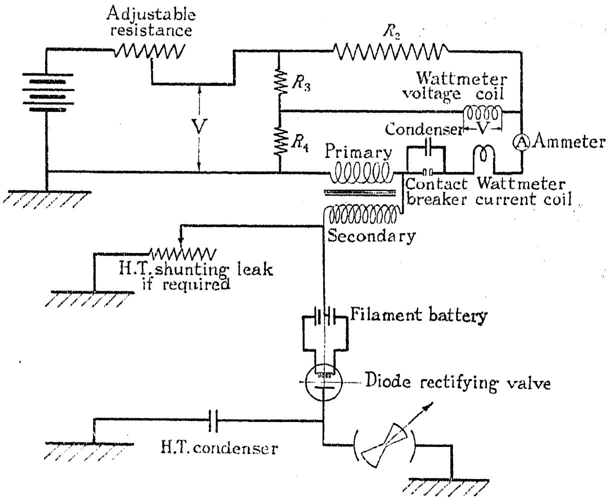

FIG. 27.—Connections for standard ignition-coil test.

The following method of testing has been found of great value in enabling these quantities to be quickly and accurately determined. The arrangement of connections is shown in Fig. 27 and consists in what may be termed a " differential wattmeter " method of measuring directly $\frac{1}{2}L_1I^2$, the energy stored in the core of the coil, and of separating this from the I^2R loss which occurs concurrently. This stored energy is at the same time compared with the coil performance, as determined by a rectifying valve and high-tension electrostatic voltmeter with or without a shunting leak. The coil, it will be noted, is supplied with current from a battery through a contact breaker and condenser, in the ordinary way, with the addition of two resistors, one a " substitution " resistor of fixed value, equal to the ohmic resistance of the coil itself, the other a variable one serving to control the current flowing. The speed of the contact breaker is so adjusted as to give time for the current in the circuit to attain its maximum and steady value before break. A suitable wattmeter has its current coil in the main coil circuit while its voltage coil is joined to the common point of two resistors R_3 and R_4 connected as shown. One end of the secondary is earthed either directly or through the primary, while the free end is connected through a rectifying valve to a high-tension electrostatic voltmeter shunted by a condenser of capacitance large compared with the interelectrode capacitance of the valve.

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* " The Effect of Hydrocarbon Vapour on the Contact-Points of Ignition Apparatus," *Proceedings of the Institution of Automobile Engineers*, 1927–28, vol. 22, p. 812.

If V be the applied voltage, R_1 the ohmic resistance of the coil itself, R_2 that of the "substitution" resistor, and L_1 the inductance of the coil, we have

$$V = (R_1 + R_2)I + L_1\frac{dI}{dt} \quad . \quad . \quad . \quad . \quad (1)$$

If v be the voltage on the wattmeter voltage coil, we have

$$v = R_1 I + L_1\frac{dI}{dt} - V\frac{R_3}{R_3 + R_4} \quad . \quad . \quad . \quad (2)$$

and
$$v = -R_2 I + V\frac{R_4}{R_3 + R_4} \quad . \quad . \quad . \quad . \quad (3)$$

Hence
$$2v = I(R_1 - R_2) + V\frac{R_4 - R_3}{R_4 + R_3} + L_1\frac{dI}{dt} \quad . \quad (4)$$

If $R_1 = R_2$, $R_3 = R_4$, we have

$$2v = L_1\frac{dI}{dt}$$

The wattmeter deflection is proportional to $\frac{1}{t}\int vIdt$, i.e. to $\frac{1}{t}\int\frac{L_1 I}{2}dI$, which is equal to $\frac{1}{2}L_1 I^2\frac{1}{2t}$. Hence twice the wattmeter reading gives the amount of energy stored in the circuit per second in the form $\frac{1}{2}L_1 I^2$. The energy stored per spark can therefore be found by dividing twice the wattmeter reading by the number of breaks per second of the contact breaker. Knowing the current flowing in the circuit and the energy stored per cycle, the value of the inductance can be calculated directly.

In order to determine the damping factor, two readings of the high-tension voltage are taken with the same primary and secondary circuit conditions, but with the polarity of the battery reversed. It will be clear that with the one connection the voltmeter will read the value of the first voltage peak, while with the reversed condition the second peak will be measured. Calling the first and second peaks V_1 and V_2 respectively, the damping may be expressed in terms of the ratio $V_2 : V_1$. Further, provided the damping is not excessive, so that V_1 occurs at approximately $\frac{1}{2}\pi$, we have

$$V_0 = V_1\sqrt{(V_1/V_2)}$$

where V_0 is the voltage that would occur in the absence of damping, and the damping factor (D) referred to in the paper is equal to $\sqrt{(V_1/V_2)}$.

In order to determine the value of C, the equivalent self-capacitance of the coil, we may write

$$\tfrac{1}{2}L_1 I^2 = \tfrac{1}{2}CV_0^2$$

$$C = \frac{L_1 I^2}{V_0^2} = \frac{L_1 I^2}{V_1^2} \times \frac{V_2}{V_1}$$

As all the quantities L_1, I, V_1, and V_2 are known, the value of C can be determined. A small correction is theoretically necessary in calculating V_0 if the natural damping of the coil is heavy, so that V_1 does not occur at $\frac{1}{2}\pi$, but for any reasonably well-designed coil this correction may be neglected, and has not, therefore, been given. The method of calculation of the e.m.f. curve given in Appendix A will enable this correction to be evaluated if desired. It is occasionally convenient to express the damping in terms of the equivalent shunting resistance at the secondary terminals. This may be calculated from the formula

$$R_0 = 0{\cdot}5\sqrt{\left[\frac{L_2}{C}\left(1 + \frac{1}{a^2}\right)\right]}$$

where L_2 is the inductance referred to the secondary, and $a = (1/\pi)\log_e(V_1/V_2)$. For coils of modern design, C is approximately 150 $\mu\mu$F, R_0 ranges from 1 to 4 MΩ, and V_2/V_1 is of the order of 70 to 80 per cent.

DISCUSSION BEFORE THE INSTITUTION, 5TH NOVEMBER, 1931.

Mr. D. E. Batty: With reference to the section (page 111) dealing with practical limits in coil design, the author states that the limit imposed by arcing at tungsten contact-points may be taken as 3·5 amperes. This figure is in close agreement with results for tungsten points which I obtained some years ago in the United States. The designers over there were very particular about the quality of the tungsten; they specified a density of grain of the order of 2 000 grains per mm², which was measured microscopically. They were experimenting at that time with a transformer type of coil, and I think they did not carry the investigations very far. The placing of the primary winding outside the secondary is a development which must lead to a good mechanical design. While the coil ignition system is making headway so far as the private passenger car is concerned, it is not being so generally adopted for commercial vehicles and omnibuses. This may be due to the fact that the latter are equipped with larger and more powerful engines, for which the magneto is more suitable because its energy output increases with the speed, whereas, unfortunately, that of the coil does not. I should be glad of the author's comments on this point. In the curves shown in the paper 0·5 M Ω is taken as the load on the secondary winding; I should like to know whether this figure represents a dirty or a new sparking plug.

Mr. J. P. S. Pillans: The author mentions that whereas 10 years ago the standard ignition system was the magneto, since that time it has been almost completely superseded by the coil, which is really of far earlier origin. The paper rather gives the impression that the change from magneto to coil has taken place purely because the coil is the cheaper. If this is so, certain technical advantages possessed by the magneto may have been sacrificed. For instance, the fact that the battery is more fully worked nowadays than it was in the past is an argument in favour of the magneto, although in the paper it is put forward as an advantage of the coil. The author perhaps over-emphasizes the difficulties and limitations to which the coil designer is subject, but they are very clearly brought out in Fig. 7. While it is no doubt true that the optimum winding-ratio of a coil may be determined with fair accuracy to meet any given set of reasonable conditions, it would be interesting to know whether these conditions are always realized in practice and whether the percentage of breakdowns is not higher at present than it was 10 years ago. Taking its limitations into account, does the author consider that the coil constitutes an advance on the magneto as regards reliability and efficiency, and that it is entirely adequate to fulfil all present and future requirements? If, due to the cheapening of manufacture, the magneto were to cost the same as the coil, would it lead to universal re-adoption of the magneto?

Mr. C. D. Le Maistre: Has the author made any experiments to ascertain how far it is possible to increase the temperature-rise of the coil without seriously diminishing the life of the insulating materials? Until quite recently the average life of an ignition coil was short, and when a fault developed the ordinary motorist —being unable to conduct experiments himself—had to buy a new one.

Mr. H. C. Cooper: I have recently been testing a large number of contact breakers of the types used in motor-car coil ignition sets and magnetos, these experiments being for the purpose of obtaining a contact breaker which would run quietly at high speeds. Noise is usually an indication that wear is taking place, and the comparative quietness of the various types is some indication of their efficiency. The type usually employed, particularly in connection with coil systems, has a rocker of pressed steel and makes a considerable noise at high speeds. In the course of a search for a type having a much lighter moving part, I came across two designs which are not mentioned in the paper. The first, which is a Continental product, is a very neat design and runs quietly. The bearing for the rocker-arm pin is a small bakelite block to which the spring is riveted, and the tungsten contact is riveted directly into the spring. The end of the spring, which is bent round and ground true with the axis of the bearing, forms the "heel." The second type has been used, I think, on only one type of English magneto. It has a flat spring carrying the contact, and the opening of the contacts is done by a small bakelite rod, working in the same way as the valve tappets on a motor-car engine. Both of these types seem to me to be an advance on the ordinary pressed-steel arm, or even the aluminium arm, and it would be interesting to know whether there is any reason why they should not be more widely used. I have had at various times to adjust a large number of magneto and coil points, and there has always been the difficulty that after altering the adjustment by, say, a quarter- or a half-turn, one finds that the wear has been uneven, so that two high spots come together and the two contacts cannot bed properly. In one type of breaker referred to in the paper the fixed contact is mounted on a base which swings round the centre of rotation of the rocker-arm. Wear on the contact points or fibre heel can be taken up by moving the eccentric screw without altering the bedding of the contacts. This is a very important point, particularly with tungsten contacts, which cannot be trued-up except by grinding or in the lathe. I should like to ask why magneto contact-points are almost always made of platinum, whereas tungsten seems to be universally used for coils.

Lieut.-Col. K. Edgcumbe: In Appendix C it is stated that provided the potential difference across the contacts does not exceed 250 volts it does not matter much what the actual voltage is. Does the author consider that the destruction of the points in an ordinary contact may be regarded as independent of the voltage, so long as this does not exceed the above value, or does his reasoning apply only to coils which have a condenser shunting the contacts? This question is of considerable importance to electrical engineers in connection with relays and contact-making devices in general, and any information which the author can give on the subject will be very useful.

Lieut.-Col. A. G. Lee: I find it difficult to connect the author's statement (page 113) that one of the advantages of the present type of coil is its lower self-capacitance, with the curve (Fig. 11) which shows that larger capacitance gives lower damping and a higher peak voltage. Perhaps the author would explain this point more fully. The process of discharging energy into the separate system which exists between the distributor gap and the sparking plug gives rise to a separate series of oscillations. The oscillations shown in Fig. 25 are of fairly low frequency, but when the small capacitance system between the distributor and the plug is charged up by the actual spark, very high-frequency oscillations take place. These high-frequency oscillations cause considerable trouble in wireless work. We have had to place our short-wave wireless stations, which are subject to this type of interference, some distance from main roads with their motor-car traffic. The antennæ of the wireless station on the route between Baldock and Cambridge are situated at least $\frac{1}{4}$ mile from the main road, this distance being found necessary to ensure that the receiving installation is not subject to interference from ignition systems on motor-cars. Aeroplane magnetos and their connected wiring are screened to prevent interference with the wireless equipment carried on the machines. I mention this point because I think it will be of far more importance in the future than it is at present. There are not sufficient broadcast waves available to provide for the needs of Europe, and experiments are in hand for adapting short waves to the uses of broadcasting. In the near future it is possible that very short waves will have been proved to be practicable for broadcasting, and, if so, a motor-car passing in front of one's house will interfere with reception. This may lead to a popular outcry in favour of the screening of all ignition systems, and as the alteration of existing systems is always difficult I would suggest that consideration should be given to the matter at the present time. Electrical screening of the whole system is a good remedy, but a partial remedy might be the adoption of brush instead of gap distributors, which should have the effect of reducing the frequency of the oscillations, if the brush rests on the contact sufficiently long to allow the oscillations to die out.

Mr. E. S. Ritter: The contacts referred to in the paper are made of tungsten, and I should like to ask whether silver has been tried as a substitute; if so, what are the difficulties and disadvantages of using it instead of tungsten? One of the problems associated with coil ignition is that when the engine is at a standstill current is likely to flow round the coil circuit and heat it up excessively. I suggest that the ballast resistance which is placed in series with the battery to limit the value of the current should have a high value, and that it should be shunted by a condenser of large capacitance. If this were done the steady current would be made very small, but quite a large pulse of current would pass through the coil during the time the contact-maker was closed. It would be interesting to know whether the same result could be achieved, in spite of the low ballast resistance, by the use of a number of the recently-introduced electrolytic condensers, which have a large capacitance but take up a reasonably small space.

(The author's reply to this discussion will be found on page 132.)

SOUTH MIDLAND CENTRE, AT BIRMINGHAM, 23RD NOVEMBER, 1931.

Mr. W. Burton: One of the points brought out prominently in this paper is the extreme accuracy necessary in the mechanical arrangements of the distributor. The shape of the cam and of the fibre heel are important factors in satisfactory running and in avoiding misfiring. Has the condenser any function other than that of preventing sparking at the contact breaker? I raise this point because at one time a leading magneto designer maintained that speed of break was of secondary importance only in the case of the magneto, the actual sparking effect being obtained by proper selection of the electrical constants of the magneto and the condenser. It has been observed by many automobile engineers that there is an apparent automatic advantage when a magneto is used, and that coil ignition is more sensitive to alterations in timing. I should like to ask the author whether he thinks that there is any ground for this belief, bearing in mind particularly that the magneto armature, as well as the contact breaker, is running at a lower speed when the engine is running slowly. Does the fact that the initial generator, i.e. the magneto armature, gives a reduced output at low speeds affect the case, while in the case of the battery system the energy available is practically constant at all speeds? The author states that approximately 95 per cent of private cars are fitted with coil ignition, while only a few per cent of motor-cycles and commercial vehicles are so fitted. There is no doubt that for satisfactory operation the types and method of wiring will have to be very much improved on commercial vehicles, and it is unfortunate that vehicles costing over £1 000 should be provided with such very poor wiring systems. There is a common belief that the insulation for a 12-volt system should be substantially less than that for, say, a 230-volt system. This is true only in a very small degree, and the mechanical qualities are just as important at 12 volts as at the higher value. A feature which is commonly lost sight of is the added danger of fire at lower voltages. In the case of a battery which is partly run down or which has high internal resistance, sufficient current may pass through a short-circuit to make the wiring hot, but with certain systems not sufficiently hot to blow the fuse. For this reason also, if more attention is given to the quality of the wiring, a big step will have been taken towards the fitting of coil ignition on commercial vehicles. Special coils should be designed for commercial work, and special attention should be given to wiring and batteries, the latter still being far from perfect.

Mr. J. R. Anderson: I should like to ask the author whether any direct-breaking type of contact breaker has been tried out for car ignition systems. If a direct-breaking rotary type were used it would completely solve the cam problem. The cam itself is costly and difficult to design to give the necessary "closed" period on the contacts. No cam would, of course, be necessary, and so all the problems connected with acceleration of the arm and cam-following disappear. With a cam type of contact breaker, according to the author, the "points" are separated for 33° of angular movement of the cam. With a rotary direct break this would easily be reduced to 15° or 20°, with the result that the "closed" period would be considerably increased. A contact breaker of this type should not be difficult to design. Since a small increase of resistance will not affect matters very much, steel contacts can be used instead of the more expensive and possibly more fashionable metals, tungsten or platinum. Burning of the steel contact would not affect the operation of the breaker, because the oxide is nearly as good a conductor as the metal itself.

Mr. S. C. Dinenage: I should like to ask the author what is the usual air-gap between the fixed electrodes and the rotating electrode of the distributor illustrated in Fig. 19, also what proportion of the induced voltage is required to bridge this gap, and whether the gap becomes enlarged owing to oxidization and burning of the electrodes. It would also be of interest if he would state approximately how much power is actually delivered to the sparking-plug ignition points.

Mr. E. Kurz (*communicated*): The design limitations dealt with in the paper may be summarized as follows:—(*a*) The limitation imposed by the heating of the primary winding if the coil is left in circuit. (*b*) The practical limit of the primary inductance, which at the same time represents a price limit inasmuch as a high inductance requires either a large amount of copper or a specially-designed magnetic circuit. (*c*) The amount of current determined by the possibility of arcing at the contacts. The first two limits cannot be regarded as sharply drawn, and may eventually be widened by appropriate modifications in the design, as, for example, the dissipation of the heat by a separate resistance, while the possibility of using a larger inductance might arise if the price of copper fell sufficiently. The third limit mentioned is, however, of a physical nature, and cannot be modified either by any re-arrangement of the design or by a change in the economic conditions. I should like to deal a little further with this question of interrupter arcing. The stress imposed on the interrupter contacts is a direct consequence of the amount of current passing through the contacts at the moment of interruption, and, consequently, also of the maximum primary current which would be attained if no interruption took place. If it were possible to use a larger current the coil could be made of smaller inductance, and the period of close could be decreased. This would bring with it a decreased current consumption while the interrupter was operating, and represent an improvement in the electrical system of the car.

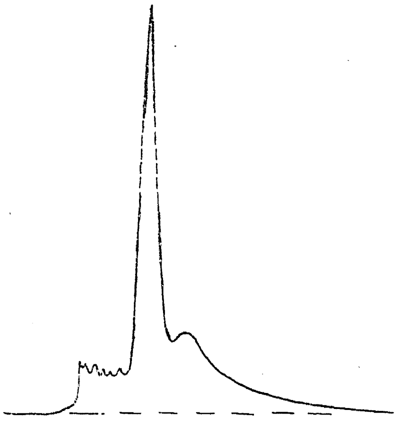

Fig. A.

It is, therefore, of importance to endeavour to find a contact material which will allow a larger current to be broken. The properties of the material could be easily described as follows:—(i) The non-oxidizing features of platinum; (ii) freedom from arcing tendency, as in the case of platinum; (iii) high melting-point; (iv) mechanical strength and rigidity of tungsten.

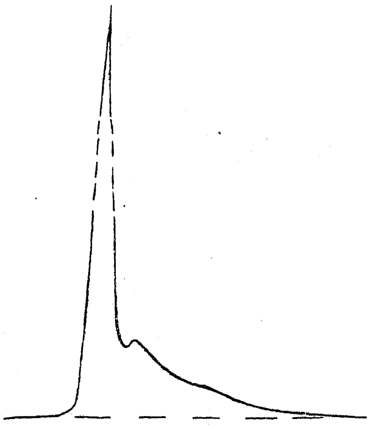

Fig. B.

Unfortunately, such a material is not available, and in coil ignition one accepts the lesser of two evils by generally adopting tungsten as the contact material, and disregarding the danger of oxidation of the contacts. New tungsten contacts usually give an extremely good performance and will permit of fairly large currents being broken, but in service they gradually oxidize and consequently show an increasing tendency to arc. While I agree that it is necessary to be careful in establishing a limit for the current which is permitted to flow through the contacts, I regard the 3·5 amperes put forward by the author as an extreme limit, and as being rather on the over-cautious side. According to my experience a current of 4 amperes, with a condenser capacitance 0·2 to 0·3 μF, can be safely permitted. This question has been thoroughly investigated by my firm, with the help of a specially-developed cathode-ray oscillograph which enables us to take photographs of individual transients, even though these are of very short duration.

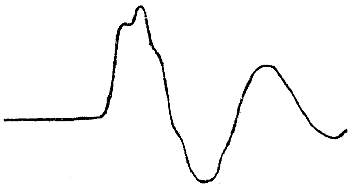

Fig. C.

The oscillograph is based on the same principle as the one built by Prof. Rogovsky, of Aachen, and is worked in conjunction with a cinematograph film enabling us to expose 25 metres of film and take 10 000 consecutive photographs. It is thus possible to investigate very thoroughly the conditions of current interruption when the circuit conditions are those corresponding to the inception of arcing.

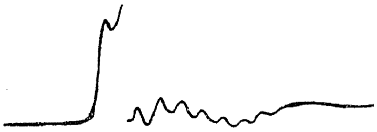

Fig. D.

An example of these is shown in Figs. A and B, which are drawn from typical oscillographs and represent the voltage across the contact-breaker points as a function of time. In Fig. A arcing has occurred, as is evidenced by the break in the line representing the rate of growth of potential across the contact points. The potential curve rises for a short distance and then remains constant for a short period while the arc occurs.

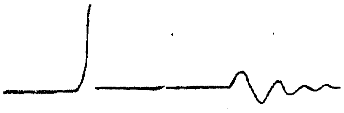

Fig. E.

This arc is later extinguished, when the potential rises and follows a more or less normal course. In Fig. B no such initial break in the line takes place, and the potential rises immediately to its maximum value. In investigating the relation of contact-breaker arcing to the conditions which contribute to its occurrence, we have based our observations on the examination of a large number of oscillograms taken in this manner, and from the evidence which these diagrams have given us arrive at our figures for the safe current which can be interrupted by a contact breaker. The same oscillograph has also been used for investigating the conditions on the secondary side of the coil, and it may be of interest to give some of the oscillograms obtained in this manner. Fig. C is drawn from an oscillogram representing the voltage wave in the secondary circuit when no spark occurs. The curve shows a damped wave, as predicted by the author, but it further reveals the small peaks superimposed on this due to the independent oscillations of the primary and secondary circuits, as predicted by Prof. Taylor-Jones's theory. Fig. D is similar to Fig. C, but in this case a spark occurred at the second small peak on the first quarter-wave, the voltage afterwards falling practically instantaneously. Fig. E is similar to Fig. D, in that a spark occurred, but in this case a spark took place at the first peak in the quarter-wave instead of at the second. In Figs. F and G multiple sparks occurred in the secondary, the current ceasing after the first spark before the whole of the stored energy had been discharged; further sparks occurred as this energy was delivered to the secondary terminals. Finally a pulse of energy was delivered to the secondary terminals which was not sufficient to bring the voltage up to the sparking point, and a damped wave occurred as the stored energy gradually decayed.

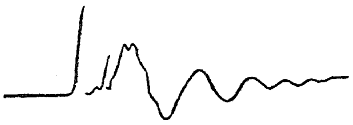

FIG. F.

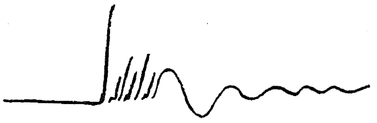

FIG. G.

THE AUTHOR'S REPLY TO THE DISCUSSIONS AT LONDON AND BIRMINGHAM.

Mr. E. A. Watson (*in reply*): The question of the relative merits of the coil and the magneto has been raised in various forms by several speakers, notably Mr. Batty and Mr. Pillans. While I should like to dissociate myself as far as possible from any discussion of this still thorny problem, I might perhaps say broadly that where the question of expense, both as regards the ignition equipment itself and as regards its installation on the engine, does not arise, the magneto as a self-contained, replaceable, and serviceable unit has claims which cannot be ignored and which may lead to its retention on certain classes of commercial vehicles. On the other hand, a mere equality in cost as between the ignition systems themselves would not lead to the adoption of the magneto on the small high-speed 6-cylinder engines which are to-day so common on private cars. To secure this it would be necessary that the magneto should be capable of as simple installation as the coil-ignition distributor. That is, it would have to furnish satisfactory ignition when driven at camshaft speed, and not be appreciably heavier or more bulky than its competitor, while its moment of inertia and driving torque must be such as to enable it to be driven through the same gears without risk of noise. These conditions are, I think, extremely unlikely if not altogether impossible of attainment.

As regards the technical points raised, I can perhaps make somewhat more definite statements. In the first place, the increased energy given by the magneto at high speed is definitely of no value even with the largest engines, and, in the second place, the limitations in design of the coil which I have dealt with in the paper do not involve any limitation in its reliability. As regards the first point, I might say that in many modern magneto designs steps have been deliberately taken to restrict and even to reduce the output at high speeds (by control of armature reaction), so that the characteristics of the two systems are very little different. As regards the second point, reliability is in general a question of workmanship and of factor of safety in insulation. Assuming an equal standard of the former, it is obviously easier to provide a larger factor of safety in the coil, where space is virtually unlimited, than in the restricted space available on a magneto armature.

In reply to the other points raised by Mr. Batty, the question of grain size of the tungsten contacts is naturally an important one, although the full connection between the micro-structure of the contact surfaces and their behaviour under various conditions has not as yet been completely worked out. It is, however, generally agreed that a fine-grain structure is advantageous, and for this reason the contacts invariably take the form of sections cut from swaged rod instead of discs stamped from sheet. The object of this is to obtain an orientation of the crystal grains in a direction at right angles to the contact face, with the object of getting the maximum grain density in the face itself.

In regard to the transformer type of coil, this, as Mr. Batty suggests, was of American origin but only had a relatively short vogue even in that country. It has not, I believe, been used in England. On the Continent it has been used on earlier designs, but has now also been given up there.

As regards the assumed loading of 0·5 megohm, it is rather difficult to correlate this exactly with a measured resistance of a sparking plug, generally, perhaps, because the resistance of the plug measured in the ordinary way with a steady voltage may be quite different from its resistance under the conditions of an impulsive discharge. The best one can say is that, in general, a coil ignition system which is capable, while shunted with a loading of 0·5 megohm, of giving a voltage equal to the measured breakdown voltage of the gap, as determined by a crest voltmeter, is found in actual practice to function satisfactorily without misfiring.

Replying to Mr. Le Maistre, the temperature-rise attained by a coil in normal operation is not such as to produce any appreciable ageing of the insulating material, and I have never had any instances of modern coils failing as a result of deterioration due to this cause. The temperature-rise of 100 deg. C. and upwards which is attained by most coils if left in circuit with the engine stationary might produce deterioration if this treatment were repeated frequently, but it is very rarely in the life of a car that this actually occurs. Probably with a driver who is reasonably careful, this contingency will never occur at all.

Mr. Cooper raises the question of alternative designs of contact-breaker lever in place of the orthodox type described in the paper. The first of these is a comparatively recent introduction and appears to be a promising design. Its only possible drawback is that the use of a steel spring as a rubbing member on the contact-breaker lever entails the employment of a fibre cam and it is just possible that conditions may arise due to wear of this and also in getting the necessary accuracy in its production. The second type of contact breaker to which Mr. Cooper refers was introduced by my firm some ten years ago and has been used on quite a large number of magnetos. Its only disadvantage is that the contact point is carried on the spring itself, and in the event of the fracture of the spring it is difficult, if not impossible, to improvise a repair. On the other hand, it is certainly capable of running at higher speeds than the orthodox type and also gives very quiet operation. The question of point adjustment referred to by Mr. Cooper has already been treated in the paper and he will find illustrations in Fig. 22B. As regards the contact-point material, tungsten is to-day generally employed on magnetos as well as on coils, and it is only when the current to be handled exceeds the carrying capacity of tungsten that recourse is occasionally had to platinum-iridium alloys. The question of contact material was also raised by Mr. Ritter. Silver is possible as a substitute, and more than one motorist in the past has made temporary repairs with silver contacts in order to get home, but the life of silver contacts is very much shorter than that of either platinum or tungsten, probably because of the low melting-point of the metal.

Col. Edgcumbe raises the question of the voltage on the contact points. I should hardly like to extend the arguments given in the paper to the case of contact points which were not shunted with a condenser, and indeed it seems to me that it is very difficult in such a case to define what the voltage across the contacts will be. If no condenser is present and the current is interrupted without an arc or a spark, the interruption must theoretically be instantaneous, and the voltage would therefore attain a very high value. Hence, in the absence of a condenser, sparking or arcing seems to me to be unavoidable, although its duration may be very short.

Col. Lee is unable to reconcile the statement that a low self-capacitance is advantageous with the statement that a large capacitance gives reduced damping. The explanation is that a low self-capacitance increases the value of V_0 more rapidly than it reduces the value of V_1/V_0, so that the net result is that V_1 increases as the self-capacitance decreases. Col. Lee also raises the question of the high-frequency oscillations which accompany each spark, and emphasizes the interference to which these may give rise in connection with wireless reception. I think, however, that the oscillations to which he refers are due, not, as he suggests, to the employment of a spark gap in the distributor, but to the whole secondary system becoming charged to a potential of anything between 5 000 and 10 000 volts and discharging suddenly when the spark occurs. Although I have no exact data, I do not think that the disturbance due to these oscillations would be minimized to any appreciable extent by the use of carbon-brush distributors. The complete screening of the ignition system on a car is a very inconvenient and expensive complication, and it is to be sincerely hoped that the necessity for this will not arise.

In reply to Mr. Burton's queries, the function of the condenser in a normal ignition system is primarily that of arc suppression. The conditions are admittedly different where the coupling between primary and secondary circuits is not very close, and where interaction of primary and secondary oscillation frequencies occurs. In this case the interchange of energy between the circuits involves the value of the primary capacitance, and an optimum value can be found which will give the best secondary performance. As the coupling is tightened, this optimum value falls until it becomes less than that required to secure satisfactory arc suppression, so that in normal apparatus the latter condition alone determines the capacitance which is adopted. Further, provided that the condenser is functioning correctly, the speed of break—at all events within limits—is without any influence on the rate of interruption of the circuit and the operation of the coil. The supposed automatic spark advance with speed, which is sometimes claimed as a property of the magneto, simply does not exist. With both the magneto and the coil the spark occurs approximately 0·1 millisecond after the contact points separate. The question of the increase in spark energy with speed, which is a characteristic of some magnetos, has already been dealt with in my reply to Mr. Batty's remarks.

In his reference to the necessity for improved wiring systems where coils are fitted to commercial vehicles, Mr. Burton brings out the weak point of all coil systems and the undoubted advantage of the magneto, where great reliability under adverse conditions of installation, service, and maintenance, is essential. The magneto is a robust, reliable, and readily-serviced piece of apparatus, the functioning of which bears no relation to the rest of the equipment. In its development and construction are embodied the results of many years' service. Its internal electrical connections, comparatively few in number, are made by trained operators in a manner which, as experience has taught the manufacturer, will not expose them to risk of fracture as a result of vibratory and other stresses. The coil system, on the other hand, can easily be put out of commission by a fault at any point in a complicated wiring system which has possibly been connected up by a wireman who has not such an intimate knowledge of the possible causes of failure, and which is in any case subjected to possibilities of damage by vibration, chafing, and flexure of the body of the vehicle, to which the internal connections of the magneto are not exposed. There is no doubt that the wiring systems of many cars and, to a less degree, of certain commercial vehicles, leave much to be desired. At the present day, when so many of the auxiliary services, as well as the ignition, depend on the wiring of the vehicle, too much attention cannot be given to this important point. It is absolutely true that the mechanical factor of safety necessary to ensure reliability will involve the provision of insulation which is at least equivalent to that used on a 230-volt circuit, and a properly-installed system should be capable of passing the same voltage tests. The only exception one could make is in the case of switches, where it is undoubtedly safe to work with less contact separation and with slower motion of the contacts than on a high-voltage circuit. I do not, however, see the necessity for the provision of special coils to meet the conditions of commercial service, in which the electrical conditions to be met with are no more severe than on private cars. In the case of the distributor it may be advisable to take special precautions to increase the durability of the parts subject to mechanical wear and to make the whole mechanism capable of withstanding rough and unskilful handling, but as regards the coil itself these conditions will scarcely arise.

Mr. Anderson raises the question of a "wipe" type of contact breaker as opposed to the orthodox pattern. I think that the answer to this is twofold; first, the unsuitability for the contact-point materials of any metals other than those of high density, high melting-point and freedom from oxidation, and, secondly, the fact that in any contact breaker of this type the break occurs between two edges, i.e. line to line, instead of between two surfaces of finite area. Even though these edges were made of a resistant material such as platinum or tungsten, the result would, I think, be a progressive burning-back of the edge, with consequent variation in the moment at which the circuit was interrupted.

In reply to Mr. Dinenage, the usual gap between the fixed and rotating electrodes of the distributor is of the order of 0·25 mm, or 0·010 in. The actual voltage required to jump this gap is of the order of 1 500 volts, but this voltage must not be added directly to the plug voltage, as in a sense the two voltages are not in phase. The spark between the distributor electrodes occurs a very minute fraction of a second before the main spark, as the result of which the gap at the distributor becomes ionized and conducting before the voltage on the plug rises to its sparking value. Actually, the voltage required from a coil or magneto is only increased by some 200 or 300 volts by the interposition in the circuit of a distributor, which in itself requires 1 500 volts to spark across. In reply to Mr. Dinenage's second query, the energy usually delivered to the plug points is of the order of 0·01 to 0·02 joule per spark.

I am particularly interested in Mr. Kurz's contribution, and I think that he and I are probably really in agreement as regards the safe primary current which can be allowed. It has usually been the practice of the firm with which I am associated to estimate the primary current on the basis of the nominal voltage (6 or 12 volts, as the case may be), although in actual service the voltage generally rises slightly above this figure before the speed reaches a sufficient value to cut down the current appreciably. If this be taken into account, the figures given by Mr. Kurz and ourselves are, I think, reconcilable.

The oscillograms showing the secondary voltage are interesting, more especially Figs. C and D, as they reveal the magnitude of the error which has been made in the paper by including the independent oscillations of the two circuits and assuming that the coil functions as a close-coupled system. The secondary wave in Fig. C does not really depart very far from the sine form, and under the conditions I think that the assumptions which have been made are justified. The oscillograms showing the multiple sparks are of particular interest, as they indicate the high-frequency surges which must be set up under many conditions in an ignition system, and the necessity of providing adequate insulation in the windings to withstand such surges.

POWER STATIONS AND THEIR EQUIPMENT.*

By I. V. Robinson, Wh.Sc.

TURBINES.

Size of Turbine Units.

The author of an earlier review† stated that power station design went forward by surges and that between each successive wave the industry was busy consolidating the position before advancing further. Since the date of the last review‡ there has been a period of consolidation, no increase having been made in the size of the largest unit installed or under construction. Nevertheless, a very large number of sets have been ordered with capacities of from 50 000 to 100 000 kW, and several with capacities of from 100 000 to 140 000 kW. Whereas three years ago there appeared to be a tendency in America to order sets of 160 000 kW and upwards, this phase seems to have passed and the tendency at the present moment is to order the largest single-axis machines that can be manufactured and, what is still more difficult, transported. It has also been suggested that the maximum size of unit should not exceed that which can be installed in one boiler unit, this leading to a limit of, say, 80 000 to 100 000 kW.

In Great Britain the maximum sizes now under construction have a capacity of 75 000 kW and run at 1 500 r.p.m.

On the Continent no machines of a greater capacity than 75 000 kW have been installed since the date of the last review, but quite a number of machines with a capacity of 50 000 kW have been ordered for various stations. For one of the Paris stations a 50 000-kW set running at 3 000 r.p.m. is under construction. This machine is provided with three low-pressure exhausts, and it is stated that with four exhausts 80 000 kW can be obtained without any undue sacrifice of efficiency.

In the three areas—Great Britain, America and the Continent—there has been a distinct tendency in the last two years to avoid the installation of cross-compound or multi-axis machines. These are not as cheap as the single-axis machines, and the gain in efficiency is insufficient to compensate for this extra cost. The large volume of steam beyond the control of the high-pressure governor—particularly in re-heat turbines—constitutes a serious menace and, to safeguard the plant, expense has necessarily to be incurred.

Turbine Operating Conditions.

As regards steam-operating conditions in Europe, with the exception of one or two plants there was, 3 years ago, no boiler at work with a pressure greater than 1 400 lb. per sq. in. Since then there has been installed a boiler of the Benson type at a well-known station in Belgium (Langebrugge), and an 1 800-lb. plant in Czecho-Slovakia (Trebovice). In the Belgian station the steam is generated at the critical pressure and is supplied to the turbine, after superheating, at a pressure of 2 800 lb. per sq. in. Further reference to this boiler will be made later in this review.

An installation at the Witkovitz Iron and Steel Works, Czecho-Slovakia, where a pressure of 1 700 lb. per sq. in. was used, has been extended by a turbine of 36 000 kW capacity and the boiler pressure has been raised to 1 800 lb. per sq. in.

Whilst with these exceptions no new plant with a pressure in excess of 1 400 lb. per sq. in. has been installed, there has been a considerable number of units set to work in the United States with pressures of from 1 000 to 1 400 lb. per sq. in. In Great Britain a plant is now being installed in the new factory of the Ford Motor Co., to the east of London, with a working pressure of 1 200 lb. per sq. in. and designed for 1 400 lb. per sq. in. In addition, a 1 100-lb. installation belonging to the Bradford Corporation is now in operation.

Apart from these extra-high steam pressures, there seems to be a tendency for sets of about 50 000 kW to adopt a pressure of 600 lb. per sq. in., and, doubtless, the recommendation of the British Standards Institution that there should be three standard pressures, viz. 200, 400, and 600 lb. per sq. in., has had a considerable effect in Great Britain in guiding engineers to accept the higher figure for the 50 000-kW sets. For sets of from 20 to 25 000 kW a pressure of 400 lb. per sq. in. has been largely used. Pending further experience, the British Standards Institution are not making any recommendations for pressures exceeding 600 lb. per sq. in.

As regards the maximum steam temperature, 932° F. at Langebrugge still remains the highest in Europe. There has, however, been a trend in an upward direction. A British firm has supplied a 10 000-kW set to Detroit designed to work with steam at 1 000° F. It is understood that the machine is not yet operating at the full temperature,† as it is deemed wise to work up to that temperature slowly. Whereas it was probably correct to state three years ago that temperatures of 700° to 750° F. represented the upper limit which the average engineer was prepared to accept, the limit should now be placed at 750° to 800° F. One Continental maker states that about five-eighths of his output in the last year has been for steam temperatures between 400 and 450° C. (752° to 842° F.).

Very considerable investigations have been made into the problem of creep, which is so important in connection with high temperatures, and definite knowledge is gradually being evolved as to the maximum stresses permissible with various materials under various operating conditions. Cylinders of cast molybdenum steel are being generally used with temperatures of 850° F. and upwards, and are stated to be satisfactory.

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* A review of progress. Reprints in pamphlet form, price 1s. each, can be obtained from the Secretary of the Institution.

† *Journal I.E.E.*, 1926, vol. 64, p. 485.

‡ *Journal I.E.E.*, 1929, vol. 67, p. 183.

† The temperature had reached 975° F. late in October 1931.

Speaking generally, it may be said that there are two schools of thought on the subject of steam conditions. The more conservative does not go beyond such pressures as, with a suitable initial temperature, do not give excessive moisture in the low-pressure part of the turbine. The other school goes beyond this and adopts pressures that necessitate reheating of the steam after partial expansion. The former leads to about 600 lb. and 800° to 850° F., whilst the latter generally halts at 1 200 to 1 400 lb. with the same temperatures. Beyond this latter figure there are pioneer plants. There are very few sets between 600 and 1 100 lb. Any intermediate pressure is usually selected due to consideration of the requirements of steam for heating or process work. In such plants there are many intermediate pressures, i.e. 700 to 800 lb. in the North of England, 950 lb. at Brunn, etc.

The position as regards reheating is peculiar in that in theory most engineers condemn it, but if extra-high pressures of 1 000 lb. per sq. in. and upwards are to be used reheating is unavoidable. This general condemnation probably arises from the fact that engineers have not yet definitely decided upon the best method of reheating the steam. Many reheat by heat exchangers using fresh steam from the boilers. This method is adopted with the 1 200-lb. British set mentioned previously. In a large number of cases the steam is taken back to special reheat boilers or to reheat sections in the main boilers; this involves some pressure-drop and some loss by radiation, and requires bulky pipes and valves. Another suggestion that has been put forward is to use oil as a heat conveyor from the boiler to the steam in the immediate neighbourhood of the turbine. As diphenyl oxide has been used as a heat conveyer in the economizer section of the boiler, it may come to be used for reheating steam. Further experience regarding the method of reheating is essential before engineers agree upon the best way of carrying out this work.

Before leaving the large turbines, reference should be made to the steeple compounded machine, which has been developed in the last two or three years. As originally designed this consisted of a high-speed, and therefore comparatively small, high-pressure unit of such dimensions that it could be mounted upon the alternator of the low-pressure, low-speed portion of the set. This was adopted, so it is stated, to save floor space, but it would appear doubtful whether the gain in this direction is sufficient—except in very exceptional circumstances—to compensate for the inconvenience which must arise from the greater difficulty of overhauling and repairing the plant. This type probably represents only a passing phase, although it has been made in units up to 110 000 kW.

MEDIUM-SIZE AND SMALL TURBINES.

For central-station work, owing to interlinking and the general growth in systems there is not much demand for steam turbines of less than 15 000 kW capacity. As regards ordinary industrial installations, few require units of greater than 4 000 to 5 000 kW capacity. Industrial turbines for works requiring process steam may be of considerable size, as for such combined loads turbines are a better proposition than purchased power. In the Detroit district, according to the chief engineer of the supply company serving that area, many paper and similar works are installing private plants and abandoning the public supply. Further reference is made to this combined demand later in this review. Between 4 000 and 15 000 kW, therefore, very few units other than pass-out turbines have been ordered recently.

For industrial plant up to 4 000 kW there has been a distinct vogue in the last three years for units of the so-called "combined" type. In this the turbine is mounted directly upon the condenser and drives a generator or alternator through gearing. In most of these units the circulating pump is driven from the extension of the generator shaft, and the other auxiliaries are driven directly from the turbine or low-speed shaft of the reduction gear. The whole unit is so designed that it can generally be erected upon a concrete raft. From the extent to which this type of plant has been taken up by different makers it would appear to have substantiated the claims that have been made for it.

As regards the general performance of steam turbines, reference should be made to the interesting and voluminous statistics contained in the last report* of the Prime Movers Committee of the National Electric Light Association, in which full data are given regarding the performance of 324 turbines having an average capacity of nearly 35 000 kW.

MERCURY TURBINES.

The progress of the mercury-vapour turbines is a matter of general interest. The 10 000-kW set at Hartford is operating satisfactorily, the overall consumption per unit generated on both mercury and steam turbines being under 0·75 lb. of coal. Two sets are under construction with capacities of 20 000 kW each, this being the output of the mercury turbine alone. One is to be placed in the makers' works, where the whole of the 240 000 lb. of steam raised by the exhaust mercury is to be used. The other is for Kearney, New Jersey.

PEAK-LOAD TURBINES.

The use of turbines with high overload capacities beyond the most economical load has been considered, but no marked progress has been made. The late Sir Charles Parsons examined the possibilities fully in a paper† presented at the Berlin World Power Conference in 1930, and reported favourably. Reliance upon old stations working only a few shifts in the winter appears to be neither an ideal nor even a commercial solution.

On the Continent a few variable-pressure turbines working in connection with thermal-storage accumulators have been installed. One of these, a 2-cylinder, 20 000-kW turbine, was designed to use boiler steam at 20 atmospheres and also accumulator steam at pressures varying between 13·0 and 0·5 atmospheres. In another case, a 6 000-kW turbine was installed in works which took their normal supply from the main and used the turbine on peak loads. Steam from a small boiler was fed into an accumulator. When not generating, this set is used for power factor correction, cooling steam being admitted to the turbine.

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* National Electric Light Association Publication, No. 151, August 1931.

† *Transactions of the Second World Power Conference*, 1930, vol. 5, p. 187.

FEED-HEATING.

Nearly all turbines, except the smaller industrial ones, are arranged for feed-heating. For the usual working pressure a final feed-water temperature of 300° to 340° F. at the maximum load is usual for units of 25 000 kW and upwards.

In one well-known Continental station (Klingenberg) some years ago the main turbines were not provided with tappings, but special turbines were installed in which all the steam was used at various pressures for feed-heating. This does not seem to have been of sufficient advantage to merit repetition, and tappings on the main turbines are now universal. One advantage is that, due to the reduced volume of low-pressure steam at exhaust, the output of a set can be increased without any increase in the size of the exhaust annulus.

INTER-STAGE DRAINING.

All turbine makers are trying some method of inter-stage draining to improve the performance of the later expansions. No one appears to be able to state what benefit is obtained by this plan, although it is considered to be an improvement.

TURBINE ROTOR MATERIALS.

When it is appreciated that, in order to find anything that moves more rapidly than the longest blade in a large modern turbine, it would be necessary to leave terrestrial things and enter the celestial realm, it will be appreciated that sound materials are needed in turbine construction. The result of failure is so great that enormous pains are taken to ensure sound designs and, what is even more important, correct treatment during forging. There appears to be some variation either in the material used or in the terms used to describe it, but for the most highly-stressed rotors a nickel steel is used with a tensile strength of 38 to 40 tons, 28 to 30 tons yield, 20 per cent elongation, and 40 per cent reduction in area.

As regards blading in large turbines, three zones have to be considered. In the high-pressure part a 5 per cent nickel steel is satisfactory, but further down the expansion (i.e. at the dew point) rustless steel containing about 12 per cent chromium and perhaps about 0·7 per cent nickel is used. For the last row this has proved to be unsatisfactory, as it does not withstand the mechanical erosion due to water at high speed. The experiment is now being made of covering the blade with chromium plating, tungsten, stellite, nitralloy, etc. More time is needed before any judgment can be given as to the success of the experiment.

ALTERNATORS.

CAPACITY.

Alternators have developed more rapidly than turbines. The large multi-axis machines of 2 or 3 years ago did not need very large alternators, and one set with a single 160 000-kW alternator had superimposed windings each of half capacity. In America there are now single units with capacities of 200 000 kVA at 1 800 r.p.m.

There has been no increase in the maximum generating voltage, 33 000 volts still being the highest in use. Generation at this voltage has been going on in a London station (Brimsdown) for 2 or 3 years. As transformers are needed for the majority of installations it is preferred to use the more customary 11 000 volts, requiring only one stator coil per slot. If it were necessary to switch at the generator voltage, the higher generator voltage would be advantageous, but this is not required in the majority of cases.

The size of alternators is closely connected with the method of ventilation adopted. With internal fans there is a limit to the capacity. This can be greatly exceeded if separate fans—either motor-driven or on an extension of the alternator shaft—are supplied. This latter arrangement increases the total length of the set, already very great; on the other hand motor-driven fans can be duplicated and they also make it more simple to adjust the air supply to the load, thus economizing in auxiliary power and giving an improved partial-load efficiency.

Whilst many makers adopt separate fans for machines above 30 000 kW, others go much further with internal fans. One large maker is able to offer a standard internal-fan design up to 125 000 kVA at 1 600 r.p.m., but is prepared to double this capacity with external fans.

COOLING.

Closed-circuit surface-air coolers are now universal. Some types of coolers are arranged with double water-circuits—condensate and circulating water—although one large firm reports that in their designs condensate is rarely used on account of the piping complications nullifying the thermal gain.

The most interesting cooling development is the use of hydrogen instead of air. This was commenced with synchronous condensers, which could be entirely enclosed in a gas-tight casing. To enable hydrogen to be used in alternators, the following items had to be provided: (*a*) A suitable gland to prevent gas leakage; (*b*) a satisfactory gas-tight enclosure with provision for cooling the hydrogen; and (*c*) gas-control apparatus to ensure that lost hydrogen is automatically replaced by hydrogen. Due to the density of hydrogen, the windage losses are reduced, with a consequent increase in efficiency. There is little, if any, corona effect upon the insulating material. Such a machine, being totally enclosed, is very suitable for outdoor stations, to which reference will be made later.

Owing to the increase in size of individual alternators and the many demands upon basement space for feed-heating plant, etc., the air-coolers have in some cases been placed on the turbine floor-level and incorporated in the stator. With such arrangements the motor-driven blowers have occasionally been either mounted upon the top of, or practically enclosed in, the coolers. As a result, the appearance of the unit is very different from that to which we have been accustomed.

Alternator Fire Precautions.

As to the inclusion of safety precautions against fire, opinions vary. Some engineers consider that the immunity from breakdown of stator windings renders the fire risk so small that precautions are not necessary, but are merely matters of personal preference. Others state that they invariably provide end-bell connections for the introduction of CO_2 or steam.

CONDENSING PLANTS.

General.

Owing to there being no change in turbine sizes there has been no increase in the size of condensers; indeed, the average surface in each separate shell has probably decreased. Two causes operate to this end. In the first place turbines are very often of the multi-exhaust type, requiring smaller individual condenser shells, and, secondly, each square foot is now capable of a higher rating. However, at least one recent condenser has about 100 000 sq. ft. in a single shell.

As to the shells, whilst cast iron is still employed, steel is widely used for the larger plants and will probably be used to a greater extent as welding becomes more general. Welding for condensers, as for so many other items, is a very promising development, and, incidentally, should render shell air-tightness easy to attain.

In America single-pass condensers are almost universal for the larger plants and even down to 30 000 kW. One informant states: "We use single-pass wherever possible, 2-pass when we have to." In Great Britain there is a very different attitude, single-pass condensers being a rarity. On the Continent there are numerous examples of the latter.

The steam-jet air-extractor is generally used, to the entire exclusion of the other types of extractors. For larger plants the extractors are often of the 3-stage type. Some makers prefer a jet inter-condenser after the first-stage extractor, claiming that the pipe connections are simpler in this case.

Air Leakage.

De-aerators are generally fitted for the treatment of the make-up water. In some American stations the air leakage on each plant is measured by a bus main and a dry vacuum-pump delivering into an air bell. Others use a calibrated nozzle with a pressure-gauge on the discharge to atmosphere from the final stage of the extractor. An indication of 5 cub. ft. of free air per minute on a plant of any size is regarded as sufficient to justify a search for the leak.

Some condenser builders, believing that air enters the steam space of a condenser with the circulating water through leaking tube-glands, have adopted a condenser with the tubes expanded at both ends. To relieve the tubes of expansion strains a flexible diaphragm is used to connect one tube plate to the shell.

Condensate Temperature.

Probably the most noticeable advance in condenser design lately has been the various devices and arrangements adopted to secure the highest possible condensate temperature at the base of the condenser. A well-known Continental designer set the ball rolling when he adopted a design which interposed only a shallow bank of tubes across the steam path, and led the condensate away from the steam path as rapidly as possible. This has been followed by other designs which allow incoming steam to have access to the condenser bottom, either by direct lanes through the tubes or by circumferential paths. A condensate temperature equal to the temperature corresponding to the vacuum at the inlet to the condenser is now usual, and a surplus of a few degrees F. has been obtained with some designs. It is perhaps unfortunate that these condenser developments should have occurred just when feed-heating by tapped steam has become so usual, and therefore when a few degrees more in the temperature of the condensate at the condenser base are not so valuable as formerly.

Tube Vibration.

Considerable experimental attention has been given—particularly in Great Britain—to the subject of tube vibration, and it is now possible to reproduce condenser conditions with various pitches of supporting plates and various clearances round the tubes in the plates, and to observe the actual mode of vibration. Observations agree very closely with theory. It is suggested that the distance between plates should not be more than 70 diameters, with a clearance of 0·006 in. round the tube.

Air Coolers.

Air coolers of ordinary condenser tubes are still incorporated in nearly all designs of condensers. While it is recognized that finned tubes are needed to ensure adequate air-cooling of generators, no serious attempt has been made to adopt these more efficient tubes in the air-cooler sections of surface condensers. One firm has used large cast-iron gilled tubes in a separate chamber.

Jet Condensers.

Jet condensers have vanished from central-station practice. Whilst units up to 20 000 kW have been installed in the past, no plant has been installed in recent years. An additional reason to that of the saving of condensate is probably the improvement in surface condensers, whereby the difference between the vacuum temperature and the circulating-water inlet temperature is reduced to a value as low as that given by jet condensers, i.e. usually from 21° to 25° F. for surface plants, although 19° F. has been utilized occasionally.

Feed-Heaters.

Whilst dealing with condensing plants it is perhaps suitable to refer to the feed-heating systems. As stated, a feed-water discharge temperature of 300 to 340° F. afte the final heater is quite usual for larger plants. The number of heaters varies, the temperature-rise in eac being about 60 to 80 deg. F. One heater is frequentl arranged so that it may be supplied with the mad vapour from the evaporator, which is the means o introducing the make-up water into the system. Whe the evaporator is not working, this heater is supplied wit steam from a turbine tapping. Feed-heaters are usuall designed for a temperature difference between the steam supply and the condensate discharge of about 15 deg. F. A larger difference gives a cheaper plant but one which is less efficient thermodynamically, and vice versa.

Examination of the diagrammatic lay-outs of many stations indicates that it is usual to install the boiler feed-pump after a heater when the temperature reaches approximately 230° F. In high-pressure plant a booster pump is generally installed at this point and the feed pump placed later in the cycle so as to reduce the cost of the heaters, and, in large installations, to make these easier to design. A large heater for a feed-pump discharge pressure suitable for a 1 200-lb. per sq. in. installation has to withstand an extremely high load on the end cover. To overcome this trouble at the Hams Hall station, Birmingham, the high-pressure heater was divided into two shells working in parallel on both steam and condensate sides. This design is not likely to become general.

Examination of the various feed-water systems promises to become easier as a result of the general adoption of standard symbols for component items, as recommended by the International Electrotechnical Commission and to be adopted by Great Britain and other countries which are associated with that organization.

TRANSFORMERS.

Limiting Outputs.

Pride of place for the largest 3-phase transformers is taken by Great Britain, with its transformers for the new Battersea power station, London. These are for a ratio of 11 000/66 000 volts. The specification required certain characteristics which prevented the maximum output from being obtained, and although it is only rated at 80 000 kVA it is considered that with an additional cooling unit this type of transformer could be rated at 110 000 kVA. In America the largest unit is of 100 000 kVA, but its overall dimensions are much less than those of the above-mentioned British transformers.

In Great Britain, and probably in America, transport facilities are the real limiting feature. Special trucks have been provided by the railway companies to transport transformers even smaller than those mentioned. In many cases 5-limb transformers have been adopted to reduce the height and so facilitate transport. The Institution has recently published a paper* dealing very fully with recent progress in large transformers.

Maximum Voltages.

Once the main transmission-line voltage has been determined in a system such as the British "grid," there is no increase in the maximum voltage of connected transformers. Thus, in Great Britain the maximum voltage remains at 132 kV. In the United States the maximum voltage in use is 220 kV. A voltage of 330 kV has been considered for certain negotiations in that country, but the lower figure was adopted.

Method of Cooling.

The 80 000-kVA transformer already mentioned is water-cooled with forced-oil circulation (type O.F.W.). Others, almost as large, have an air blast on the radiators and forced-oil circulation (type O.F.B.). The deciding feature as to type of cooling is, apart from personal predilections, the total cost of transformer plus cooling outfit; if the cost of the O.F.W. type be taken as 100, the O.F.B. type costs about 108. Naturally-cooled transformers could be built for sizes up to 40 000 kVA.

Efficiencies.

Always of high efficiency, transformers have tended lately to become even more efficient owing, in Great Britain, to the practice of capitalizing the value of the losses in comparing competitive tenders. Naturally the use of larger frames for a given output improves the efficiency, but at increased capital cost. A balancing of these two factors according to load factor has led to the adoption of such relative sizes that the efficiency of the largest transformers over a wide range of load does not vary much from 99·5 per cent. Even for a 4 000-kVA transformer 99·0 per cent is usual.

Voltage-Change on Load.

This has received much attention of late years. The original method of using two parallel windings has been largely superseded, and many firms now employ the single-winding method in which the change takes place with the winding under load and a preventive auto-transformer is used with the line wire connected to its mid-point. There appear to be many variations of this basic method, differing in regard to the number of load-switching operations needed to make a tap-change.

In all e.h.t. transformers it is usual with any of these methods to bring out the tappings near the neutral end of the high-voltage windings, so that the voltage to earth of the regulating equipment does not exceed 33 kV.

Surges.

The larger number of storms in America have perhaps rendered protection against surges a more vital question than in Europe, but the problem has received attention on both sides of the Atlantic and has been solved. Trouble from lightning arises from the rapid voltage-rise at the wave-front, this causing initially great stress between the end turns of adjacent windings.

Most makers have successfully met this trouble by using a reinforced insulation for the windings. One American firm has applied artificial-lightning tests to some 42 000-kVA, 220-kV, single-phase transformers. These were so arranged that the voltage-rise at the front of the wave was of the order of 10 million volts per micro-second, whereas the slope of the steepest wave-front observed in any storm is about 4 million volts per micro-second. The transformer was not distressed by these tests.

A well-known British firm uses specially-designed insulations and interposes a surge absorber between the line and the transformer. This device reduces the steepness of the wave-front by abstracting its energy and by flattening it. The arrangement has been shown to reduce the stress within the windings by about 85 per cent.

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* R. M. Charley: *Journal I.E.E.*, 1931, vol. 69, p. 1189.

NOISE AND INTERFERENCE WITH COMMUNICATION CIRCUITS.

These features have received attention, and in this connection it is generally agreed that it is necessary to limit the induction density in the core to a reasonable value. Rigid bracing of any radiating tubes on the tank is necessary. One firm has developed an instrument for measuring tank-wall vibration and sound pressure as functions of frequency. This has not led to any very valuable modification of transformer design. In some cases it has been found possible to reduce the noise by making some changes in the substation itself, these evidently being cases of resonant vibration.

SWITCHGEAR.

GENERAL PRACTICE.

In Great Britain the "grid" has grown rapidly and its effect as a national busbar is beginning to be felt.

The effect in the major power stations is not very noticeable as regards the demands on their switching equipments, and the maximum breaking-capacity rating specified remains at 1 500 000 kVA. In smaller power stations and at switching centres, the case is rather different. The grid connection has brought with it a much increased short-circuit value, notwithstanding all precautions. Increases in circuit-breaker sizes and ratings have been unavoidable, therefore, in many instances. The cases of gravest difficulty have been those wherein, because of local conditions, the grid voltage has been stepped down to low values such as 6·6 or 11 kV in densely loaded areas. These conditions have called for switching equipments of heavy normal current-carrying capacity and also of high short-circuit-interrupting ability. In distribution work there is a tendency to call for higher breaking capacity owing to the generally increased short-circuit values.

The trend towards the use of all-metal enclosures in switchgear design has been well maintained, though some new equipments of cell-type gear are still being installed. A noteworthy feature in Great Britain is the provision of 66-kV metal-clad oil-filled apparatus for the main busbars of the new Battersea power station. The design is different in several respects from equipments of oil-filled apparatus for 33-kV service, two notable features being the manner of constructing the busbars and the method employed for isolation. Designs for 132 kV are well in hand and probably before this report is published metal-clad switchgear for this voltage will be in operation in America (Waukegan).

At Waukegan also an outdoor oil-filled switching installation for 132 kV has been built. In this the busbars and connections take the form of standard oil-filled cables, each unit being provided with its own pressure reservoir; oil-immersed isolators are employed and these are, in effect, non-automatic oil switches. They are provided with air-insulated socket devices from which they may be lowered out of contact, for greater security.

For switchgear installations of large size it is becoming usual in this country to adopt duplicate circuit-breakers for connecting generators and main circuits generally to one or other of the busbars, owing to the greater operating flexibility of this method as compared with schemes involving selector switches or plugs. In the case of moderate rupturing capacities, connection to the busbars is usually carried out by means of a transfer breaker, i.e. the particular circuit can generally only be changed-over under "off-load" conditions. In metal-clad compound-filled gear it is becoming customary to mount busbar selector switches in the draw-out member, generally in an oil-filled chamber above the breaker.

In the past the uncertainties connected with empirical design have led to circuit-breaker failures, so that a definite fire risk has been attached to the use of oil. The present practice in Great Britain is to obtain safety by furnishing containers of great strength.

Research aimed at providing a scientific basis for design is leading both to the development of improved and more reliable types of oil circuit-breaker in which such risks will be reduced to reasonable proportions, and also to alternative designs in which the use of oil will be eliminated.

The trend of experimental development in Great Britain, as elsewhere, is, however, towards a reduction of the amount of energy to be dealt with in the circuit breaker and towards more effective methods of disposing of the products of arcing. These improvements lead, incidentally, to improved life of the circuit-breaker contacts and quicker operation under the severest faults.

On the Continent, departures from the existing practice are not so noticeable, probably the main one being in respect of the circuit breakers employed. Oil-less circuit breakers of the expansion and gas-blast type have been developed commercially there, and have found noticeable application at practically all voltages up to 110 kV.

Fundamental work on gas-blast, oil-blast, and baffle circuit-breakers, amongst other designs, has been carried out in Great Britain. In America the tendency is to improve the oil circuit-breaker.

In the expansion circuit-breaker the arc is broken first in water, in an atmosphere of superheated steam. On further vertical motion of the contact member this superheated steam is allowed to expand suddenly, causing a partial condensation, which effectually de-ionizes the arc path. Circuit breakers of this type were set to work early in 1930 and experience of them has been satisfactory.

In the gas- or oil-blast switch or the oil-jet circuit breaker the aim of the designer is to introduce a supply of fresh gas or oil into the arcing space while carrying off the products of arcing and de-ionizing the arc path. Experimental short arc-gaps able to withstand 100 000 volts per inch have been produced, and commercial designs show a marked improvement in dimensions as compared with the well-known patterns of oil circuit-breakers.

Outdoor installations working at extra-high voltage show several improved features. The most notable, perhaps, is the introduction of comparatively low structures for the busbars and connections. Short ferro-concrete posts are employed to carry isolating-switch units, and similar posts are adopted for mounting busbar- and connection-supporting insulators. The cost of maintenance work is reduced very materially in stations of this kind, first by the durable character of the ferro-concrete mounting structure, and secondly by the ease with which mechanical operating parts can be inspected and attended to, due to their low elevation. As already mentioned, metal-clad switchgear has now been developed for outdoor use, being remarkably compact in both horizontal and vertical directions. It presents some advantages compared with the standard type of outdoor switchgear.

As regards the types of switchgear used in minor power stations, there is a continued movement towards smaller and more compact designs, improved insulation of live parts, reduced risk of accidental contact, and general safety and convenience in operation and maintenance work. Welded steel structures and enclosures are playing a useful part in reducing costs.

CONTROL.

The interlinkage of power generating plants brings in its train the need for centralized control in order to realize those economies which are thereby rendered possible.

In modern power stations control of all parts of the equipment is usually centralized, and the switchgear is therefore operated by means of solenoids or motors. The control room is generally provided with an automatic diagram in addition to the individual-circuit indicating lamps.

The possibilities which attend the full exploitation of the methods and devices perfected in automatic telephone work are being more fully realized by power engineers and switchgear designers, and co-operation between these specialized branches of electrical engineering has already begun.

In connection with the Central Scotland scheme of the Central Electricity Board, a switching system largely incorporating telephone practice has been adopted which enables the whole scheme to be supervised and controlled from Glasgow. Communications are automatically switched-in according to a predetermined order of priority.

The introduction of automatic electrical operation of switching apparatus to supersede manually-operated devices is all to the good. Cheaper and more reliable electrical operating units have made their appearance, and the resultant service offers also greater security and less danger to human life in the event of accidental failure of materials.

BOILERS.

CAPACITIES AND WORKING CONDITIONS.

In the last review, reference was made to a contract recently placed for boilers with a maximum evaporation of 800 000 lb. per hour. Whilst this figure still represents a large boiler, a boiler in New York (14th Street station) recently maintained an output of 1 270 000 lb. per hour on test. The majority of stations, however, do not go beyond 300 000 to 500 000 lb. per hour. In London (Battersea) several boilers of about 300 000 lb. are being installed.

As regards steam pressure, this has already been covered in the section dealing with turbines. 1 400 lb. remains the maximum, except in a few Continental stations, but 400 to 600 lb. is a popular pressure range. Over 1 400 lb. per sq. in. there are very few boilers. Amongst these is a plant in Czecho-Slovakia (Trebovice) with a pressure of 1 800 lb. per sq. in. The boilers for the 1 200-lb. turbine at the Ford Motor Co.'s London factory are designed for 1 400 lb., the safety valves are set at 1 340 lb., and the pressure at the boiler is 1 250 lb. per sq. in.

A well-known Belgian station (Langebrugge) has the highest working temperature, although an American station (Detroit) with a British 10 000-kW turbine will ultimately exceed this figure by maintaining a temperature of 1 000° F. at the turbine.

BOILER TYPES.

So far the design of boiler used for the early pressures of 200 to 300 lb. per sq. in. has proved to be quite satisfactory for 1 400 to 1 800 lb. It was thought that radical changes would have to be made and many designs have been produced which all aim at the removal from the fire zone of the actual ebullition of the water. The heating surfaces exposed to the furnace are only used for superheating purposes. In the regenerative types this superheated steam is used in non-fired external vessels to evaporate a greater weight of saturated steam, this process being frequently repeated.

On the Continent one special type of boiler (the Loeffler) has been developed in which a steam pump is an essential component. This is being tried out on a large scale in Czecho-Slovakia. The initial boilers in the installation at Witkovitz have come up to expectation, but the latest extension has not yet been at work for a sufficient time to enable any report to be given.

Reference must be made to the critical-pressure (Benson) boiler, which is of old standing but has made progress lately. The most notable example, at Langebrugge, has a normal capacity of about 220 000 lb. per hour. This boiler is working satisfactorily.

BOILER DRUMS AND MATERIALS.

The success of the normal type of boiler is due to the ability of the forgemasters to produce boiler drums of considerable size and able to withstand high pressures. The use of the old riveted drum was accepted up to pressures of about 450 lb. per sq. in., but for higher figures it was considered right to confine the riveting to the attachment of the drum ends. That construction was applicable up to 650 lb., and so covered the popular pressure range. Beyond that pressure, solid forged drums had to be used. Owing to thermodynamic reasons the next higher pressure used was upwards of 1 100 lb. per sq. in., so that the solid drum was obviously obligatory. Prior to this high-pressure boiler development, considerable experience had been obtained in connection with large high-pressure drums for the oil-cracking industry. Large solid forged drums can now be obtained that will prove to be well able to meet the demands made upon them.

Considerable attention is being given to the possibility of welding the drums. The reduced cost makes this process desirable, but there have been doubts as to the reliability of the welds, as these depend so much upon the skill of the individual welder and it has been difficult to examine them except by a test to destruction.

The subject is being closely investigated by all the main boiler-makers. Several firms have installed automatic welding-machines to make the circumferential and longitudinal joints on drums of extreme size. After welding, the drums must be annealed; the annealing furnace in connection with one welding machine was 14 ft. by 14 ft. by 64 ft. long, and it may be even larger.

As a check upon the welds, an X-ray equipment is installed. This has tubes operating up to 250 000 volts, giving a penetration of 3½ in. of boiler plate. The fact that the welding problem is being thus attacked by many of the largest boiler-makers makes it certain that the cost of high-pressure boilers will be reduced.

FEED-WATER TREATMENT.

The subject of caustic embrittlement is regarded as closely connected with materials, yet doubt still exists as to whether many cases of so-called caustic embrittlement met with in practice really fall within that category. Many cases of corrosion cracking have been classed as caustic embrittlement. Manufacturing precautions are only palliatives, the real cure being the proper treatment of the feed water and continual routine tests of the degree of concentration.

The advent of high pressures has emphasized the need for pure feed water. The cycle of development appears to have been as follows. Increased pressures required stronger economizer tubes, and steel was therefore used for these. The steel tubes were attacked by the oxygen in the feed water, and thus de-aerating plants were generally installed to eliminate oxygen, the make-up water being admitted through evaporators. The latter were used to eliminate any contained salts which would ultimately have been deposited on the boiler heating surfaces. In modern boilers the evaporation per square foot of heating surface is so much greater than previously that any deposits are to be avoided as far as possible. A pressure of 1 400 lb. per sq. in. does not of itself necessitate any better feed water than 600 lb. per sq. in. Feed water is now treated to give caustic alkalinity, and, as indicated, has to be free from contained oxygen and also from solids.

STOKERS AND PULVERIZED FUEL.

The question of size of unit is closely connected with the method of feeding the fuel into the boiler. Until the last year or two it was thought that the stoker had reached its limit with normal steaming capacities of 200 000 lb. per hour. Very shortly some boilers with chain-grate stokers will be at work in London (Battersea) with a normal capacity of over 300 000 lb. per hour, and units up to about 350 000 lb. are installed elsewhere. One maker claims to be able to supply stokers up to 38 ft. in width and to a capacity of 500 000 lb. Capacities with pulverized fuel are up to seven figures, an output of 1 270 000 lb. per hour having been sustained, as already mentioned. Apart from the greater flexibility, one advantage is that there is no limit to the temperature to which the air admitted to the furnace may be raised. Now that feed-heating to a high temperature is done economically by tapped steam, the flue-gas heat is naturally used in air heaters, making a high air-temperature possible. Thus, for large boilers pulverized fuel and water-wall furnaces are universal. For pulverized fuel the trend towards individual mills and direct firing, and away from the central system with storage, has lately become stronger. Nearly all the recent installations are of the individual-unit type, one large maker having had no orders for the other type during the past 3 years.

DUST AND SULPHUR IN FLUE GAS.

After dealing with pulverized fuel it is a natural step to consider the dust question. Even in dry atmospheres fly dust has caused trouble in the neighbourhood of the station. In England with its humid atmosphere the trouble is accentuated. Various arrangements of cyclone dust-catchers are used. On the Continent some use has been made of a wet type of catcher in which the gases impinge upon wet surfaces in series, depositing the dust thereon. No great progress appears to have been made by an electrostatic method of dust separation. It requires a large amount of space for its accommodation.

A recent trouble has been the sulphur content of the emitted flue gases. Whilst this was with us 3 years ago, it has been very much more prominent in London recently in connection with a very large new station (Battersea). The daily Press, with that little knowledge which is so dangerous, has given great prominence to the question. The engineers of the London Power Co. investigated the matter very thoroughly and were able to satisfy chemists appointed by the Government that no harm can arise from their flue gases. Experiments were made in progressive stages from a small model, then half a medium-size boiler, until boilers with an aggregate evaporative capacity of nearly 3 500 000 lb. per hour are now being equipped with the special type of sulphur-removal plant. The final form of plant consists of a vertical two-pass concrete tower with banks of catalytic-iron scrubbers in the first or down pass, and wooden scrubbers in the uptake. In the latter an alkali wash is used. This is followed by a section for the removal of free moisture from the gases, now stripped of their sulphur. The wash water also has to be treated to remove the solids, so as to ensure that the effluent is harmless. This plant follows a cyclone dust-catcher; the combination was tested when soot-blowing was being done, and found to be satisfactory. On the experimental plant the operating cost, i.e. for power and alkali, was only 3d. per ton of coal burnt.

CONTROL.

Boiler control, particularly with pulverized fuel, is becoming more centralized and is approximating to the control usual in the turbine house. In the newest stations the boiler room is clean and white, a great contrast with the early stations in which clinker was drawn on to the floor of the boiler house and dirt was deposited everywhere. Instrument panels now enable the engineer to keep a close watch upon both combustion and steam conditions, and to ensure that the boilers are operated at all times and at all loads with a minimum of excess air.

HEAT-CONVEYING MEDIA.

An interesting recent development, and one which may lead to great things, is the use in an American station

(Bremo) of diphenyl oxide as a heat conveyor. In a boiler of the single-pass type at Bremo the air-heater, if installed, would have had to be at a high elevation, entailing large and long air-ducts to the furnace. To obviate this, diphenyl oxide is passed through suitable pipes in the flues above the boiler and conveyed down to air-heaters placed in the most convenient positions in relation to the furnace. A 3-in. or 4-in. pipe thus suffices to replace the large air-ducts. Another advantage is that the primary and secondary air are heated separately to the most suitable temperatures. If extended experience confirms expectations, this chemical—or others of like nature—may be used for conveying heat to reheaters situated at the turbine.

GENERAL.

Dealing with the station as a whole and endeavouring to state the trend of affairs, the following may be regarded as the present position.

Although the world-wide trade depression has had its effect, the demand for electricity is well maintained, particularly in Great Britain. The demand is met by medium-sized units and not by larger individual units. Steam pressures are usually not greater than 600 lb. per sq. in., with a total temperature of 800° to 850° F. Turbines are always of the regenerative type, and, except for small units, generally of the 2- or 3-cylinder tandem type. In America the single-cylinder type is preferred up to 75 000 kW. Reheating of the steam is only used with pressures of 1 000 lb. per sq. in. and upwards. Generators usually work at 11 000 to 13 800 volts, but 33 000 to 36 000 volts may be used when a station delivers electricity direct to a medium-voltage network. Boiler designs are in a state of flux; the old type holds its ground well, but perhaps the new types have not yet had time for development. Switchgear is changing rapidly due to the endeavour to get maximum breaking-capacity in a reasonable space. Like transformer stations, switchgear is often placed out of doors.

In the United States greater attention appears to be devoted to capital cost than was once usual. It is no longer the object of engineers to build a station that shall be the most prominent as regards some particular feature. Now they are really considering whether any particular design or arrangement will lead to the greatest overall efficiency, i.e. the lowest all-in price for the electricity delivered from the station, or, as they call it, "dollar efficiency." Whilst this is all to the good, it is also fortunate that we still have with us some "pathfinders" who are exploring possibilities so that, later, all may benefit. To these, the whole industry throughout the world should be grateful.

Open-Air Power Stations.

One direction in which some reduction in cost is being sought is the station building. Is a building always necessary? We have been through various stages—elaborate buildings of faced brick on the one hand and galvanized-iron weather-shells on the other. In America engineers are wondering whether the building can be eliminated entirely. In a suitable climate it may be possible, but Great Britain will not be able to share in this reduction of cost. The Benson boiler at Langebrugge is out of doors, and switchgear is already placed outside. A steam turbine is a robust article, and with perhaps a local shelter at the governor end it might go outside. The hydrogen-cooled alternator is already well protected, due to the need of conserving the hydrogen, so that it would probably need no modification for outdoor use; similar constructions could be used for air-cooled machines. Hydrogen-cooled synchronous condensers have been placed outside for some time, and quite recently large frequency-changers have been installed without any roof beyond a light rain-guard.

With the modern type of central control of both turbine and boiler houses and of the switching arrangements, it would appear to be quite feasible to put everything out of doors except the actual control rooms, provided the climate is suitable.

One difficulty might be the need for overhead cranes for turbine overhauls, but this need could be met by means of a mobile crane which would span each turbine as needed and enable erection or overhauls to be executed. Boilers are now erected without any overhead crane, even though they involve weights comparable with those of turbines and alternators.

Co-operation Between Stations and Other Industries.

Suitable tariffs are being adopted with a view to lowering the total cost of production by co-operation between the station owners and other industries. These tariffs apply to long-time users of current for electrochemical and electrometallurgical purposes.

Two to three years ago an interesting example of co-operation occurred in America. Two supply companies which were about to erect a joint bulk-supply station (Deepwater) were joined by a chemical company, and all three participated in the venture. The supply company's turbines were of the 2-cylinder tandem type, but the chemical company's turbine had only the high-pressure cylinder, the steam then passing into their works for process purposes. Any power generated by the chemical company's turbine over and above their needs went to the supply companies, which were able also to supply any deficiency.

In the North of England there is an interesting installation which is entirely the property of a chemical company. This is on a sufficiently large scale to enable them to do their own balancing of heat and power demands without the aid of the local supply company. The total capacity is about 100 000 kW, and the steam pressure is 700 to 800 lb. per sq. in. with a temperature of 850° F. Some turbines are of the back-pressure type and exhaust to a medium-pressure main, some work over the complete pressure range, and others work from the medium-pressure main and exhaust at various pressures to heaters, evaporators, etc.

Recently paper works, dye works, etc., have been installing their own plant in preference to continuing on the main supply, due to their power and heat demands being met more economically by pass-out turbines. This was the situation in Brunn, Czecho-Slovakia, where the power station belonging to the Westmahrische Elektrizitäts Aktien-Gesellschaft was situated some kilometres from the town. Many of the owners of the cloth mills and dye works congregated in the centre of Brunn proposed to install pass-out turbines. In order to retain their customers the local supply company installed a station in the centre of the mill area and supplied steam to them, the pressure at the station being 130 lb. per sq. in. Boilers generate steam at 950 lb. per sq. in. and it is expanded to the distribution pressure in back-pressure turbines. Another turbine, of the condensing type, takes some of the low-pressure steam and is tapped for heating the whole of the boiler feed. As the condensate does not return to the station, town service water is used for feed; to distil the whole would have been uneconomic. Thus the supply company has retained its customers and obtained a highly efficient station.

This development naturally leads to the consideration of the many steam-supply companies in America. There are over 120 of these companies supplying steam in their immediate neighbourhood for domestic and office heating. With the advent of high-pressure boilers and turbines at a reasonable cost some of these concerns are now considering installing back-pressure turbines, as at Brunn, and connecting with the local supply company. The taking-over of the steam supply companies by the electricity supply companies would seem to be a natural development.

Could not this same idea be put into operation in London? There are some big power stations within steam-supply range of large residential areas. By selling at any price over the annual charges for steam mains, fuel, the cost of replacing the water, maintenance, etc., the supply company would be in pocket as compared with the expense now incurred in wastefully dissipating the heat in a river or in cooling towers.

In Belgium there is a striking example of a power station commencing to exploit auxiliary processes for the express purpose of improving the power-station performance by using electricity during long hours. At Langebrugge a carbide furnace, absorbing 3 500 kW, was commenced in 1926. This was a success, and now —directly or through subsidiary and allied companies—nearly 30 industries of the electrochemical type are operated around the station. The result is seen in the relative growth in consumptions. For lighting and small power they sold in 1922 about 2 500 000 units, and, in 1929, 12 000 000 units. For electrochemical work and large power users the 1922 units were 14 000 000, increasing in 1929 to 106 000 000. Originally only an electricity supply company, this concern has now become in addition a chemical company—both directly and through its holdings.

PEAK LOADS.

Some reference has been made to peak-load turbines, but there is no great progress to report. Pulverized-fuel boilers are flexible, and are suitable for peak-load plants. Condensing plants present no difficulty. Alternators must be of ample capacity unless some system of extra brine cooling be adopted. Full-capacity switchgear must be provided.

One small development which may have a great future has occurred on the Continent. Some hospitals, banks, cinemas, etc., have installed Diesel-engine sets which are arranged to start up automatically when the line voltage fails or falls below a predetermined value. This idea may be used on a larger scale on low-tension feeder lines to a distant village.

ACKNOWLEDGMENTS.

To enumerate all those who have, in response to the author's request, supplied information regarding the developments in those sections of power station practice in which they are interested, would be a lengthy performance. There would always be a possibility that some name might accidentally be omitted or that some source of information might not be acknowledged. The author will therefore confine himself to thanking collectively those numerous manufacturers, power-station chief engineers and consulting engineers of Great Britain, Australia, France, Germany, Holland, Belgium, Switzerland, Czecho-Slovakia, Denmark, and the U.S.A., without whose liberal aid this review could never have been produced. It is to be regretted that greater use could not be made of the large mass of data that has been received.

RADIO TELEGRAPHY AND RADIO TELEPHONY.*

By Colonel A. S. ANGWIN, D.S.O., M.C., B.Sc.(Eng.), Member.

A review of technical progress in the engineering practice of radio communication may conveniently be brought into perspective by a consideration of the general trend of development and the increasing variety of purposes to which radio is being applied.

Some of the more recent applications of radio, such as broadcasting, long-distance telephony, air services, etc., have now attained an importance and affect interests of at least equal magnitude to long-distance telegraphy and mobile marine services, the uses to which radio was initially applied.

In some directions radio has no competitor and no alternatives are available. In this category may be placed mobile services to ships and aircraft; direction finding for distances beyond audible and optical ranges; long-range telephony, for distances at which cable circuits are impracticable; and broadcasting. To this class television should perhaps be added, as the wide frequency band required for its adequate transmission appears economically to preclude the use of any alternative.

Radio telegraphy between fixed stations, irrespective of distance, and short-distance point-to-point radio telephony, could, however, technically be substituted by wire and cable communications. In this application economic factors are the main considerations involved in the choice of system. The relative order of importance of these various applications is becoming a matter of international interest as a result of the ever-increasing expansion of services and limitations in regard to the total number of channels available. These limitations are particularly accentuated in the short-wave portion of the spectrum, where radiation—even at low power—may result in propagation to long distances.

International rules and regulations are therefore essential in order that the different categories of services may be equitably allocated to specified bands in the frequency spectrum so that the most efficient use is made of the ether. The International Radio Convention held at Washington in 1927 formulated a code of Articles and Regulations which are to be reviewed at the approaching International Convention at Madrid in 1932. The technical aspects of these rules are studied by the Comité Consultatif International Technique des Communications Radio-électriques (C.C.I.R.), and the recommendations of this committee, the last meeting of which was held in Copenhagen in 1931,† give concise information concerning many of the important problems affecting the development of radio to which reference will be made in this review.

MOBILE SERVICES.

(a) *Marine Communication.*

The number of ships fitted with wireless apparatus in accordance with the provisions of the Safety of Life at Sea Convention is about 15 000. The rate of increase in compulsorily-fitted ships is small, as might be expected from the decline in the output of new shipping tonnage, but the gradual replacement of spark transmitters is progressing and all new marine sets of a power greater than 300 watts are being fitted with valve transmitters.

The majority of compulsorily-fitted ships using low-power apparatus and wavelengths between 545 and 830 m communicate only with the short-range shore stations situated around the coasts, and their use of wireless is chiefly confined to messages concerned with the safety and navigation of the ship. The minimum range legislated for is 100 nautical miles from ship to ship, but in practice greater ranges are obtained in working to the shore stations, either directly or by relaying through other ships.

Increasing use is, however, being made of wireless on liners, large cargo boats, and trawlers, where it is found to be invaluable for the use of passengers or for communication with owners and agents.

Many of the larger vessels are equipped for longer-wave working (wavelengths of 2 000 to 2 400 m), and transatlantic ranges are being obtained. These installations are designed for handling large numbers of messages expeditiously. Short-wave telegraphy is also being increasingly used for long-distance ship-and-shore communications. At the present stage of development considerable interference exists, since many of these installations are somewhat crude in performance as regards frequency-stability and width of emitted band. Others, however, are of high grade and employ master-oscillator or crystal control drives comparable in performance with the best land-station practice.

The difficulties involved in stabilizing the frequency of these transmitters are perhaps economic rather than technical, and one of the most promising solutions now being explored is that of operating the mobile station on the same frequency as that of the land station.

Direction-Finding.—International agreement now requires that all passenger ships of 5 000 tons and upwards shall be equipped with wireless direction-finders, and, owing to the increase in demand which this regulation involves, many new and improved designs have been introduced.

One interesting development has been the production of a direct-reading type of direction-finder, of which the following is a brief description. A receiving loop revolving at 600 r.p.m. is combined with a vertical antenna so as to produce a rotating cardioid reception curve; the loop is attached to the same shaft as a rotatable electromagnet, in the air-gap of which is fixed the moving coil of a galvanometer carrying a pointer. After amplification and detection, the received signal, from which the bearing is to be taken, is passed through the moving coil of the galvanometer, which therefore tends to set itself in the position where the flux in the air-gap of the rotating electromagnet is a maximum, i.e. in the position where the loop receives maximum signal.

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* A review of progress. Reprints in pamphlet form, price 1s. each, can be obtained from the Secretary of the Institution.

† Comité Consultatif International Technique des Communications Radio-électriques (C.C.I.R.). Second Meeting, Copenhagen Bureau International de l'Union Télégraphique, June, 1931.

The position of equilibrium depends upon the integral over one or more revolutions of the mechanical forces due to the reaction of the flux of the electromagnet on the variable flux produced by the moving coil. The direction-finder operates on the maximum rather than —as is the case when aural methods are used—on the minimum of the signal. The precision of measurement is not, however, reduced by the flatness of the cardioid reception curve at its maximum point, as would otherwise be the case, owing to the integration effect.

The rotating coil is installed on the deck of the ship, and the receiver, which has an indicator giving a direct visual reading of the bearing, is placed in the cabin or chart-house underneath the loop.

Adcock-Type Direction-Finder.—The development of this type of direction-finder has been actively pursued as the result of recent investigations* which show that it is practically immune from "night-effect" errors. The location of the apparatus at ground-level has introduced modifications in the original systems to correct for the assymmetry of the aerial systems.

The modified balanced Adcock system is now incorporated in commercial installations, and practical experience of it has shown that bearings of a high order of accuracy may be guaranteed during sunset and night periods on the range of wavelengths used for direction-finding. The Adcock-type direction-finder is not, however, suitable for installation on board ship.

Ship Telephony.—Ship-to-shore telephony limited to the respective radio terminals on the ship and on shore, i.e. without facilities for extension to the inland telephone system, has been in operation for communication to trawlers for some time and presents few technical problems. A great advance has been made by providing facilities for telephony from ships with through facilities to telephone subscribers.

In February 1930 a commercial telephone service was established between this country and s.s. "Majestic" on the Atlantic route. This was followed by the installation of equipments for similar services to several other of the larger passenger vessels. On this side a telephone service is provided through Rugby to practically the whole of Europe, whilst on the American side a similar service connected to the United States and Canadian telephone systems has been developed with the same vessels.†

The provision made for the service at the land stations has been on the same general lines as that for long-distance point-to-point telephony, with some essential modifications due to the variability of the ships' positions.

On the ship the radio transmitter and the radio receiver are necessarily located close together, whilst the transmitting and receiving wavelengths are not widely different. These factors introduced the problems of preventing the receiver from being appreciably de-sensitized by the carrier wave of the ship transmitter and of reducing the high noise-level produced from currents set up in imperfectly-bonded stays and rigging in the ship's superstructure.

The solution of these difficulties has been found in the expedient of suppressing the telephone transmitter carrier wave whilst the subscriber on the ship is not speaking. A successful method adopted for this purpose is to amplify and rectify the speech voltage and apply the derived d.c. potential to the grid of a small "keying" triode, which then starts the carrier. There is no appreciable time-interval between the starting of the carrier and the arrival of the speech voltages at the modulation input, but a resistance-capacitance circuit is introduced having a time-constant sufficiently great to maintain the potential on the grid of the keying triode, between words and phrases of the subscriber's speech, and thus avoid "clipping."

Ships fitted with short-wave telephony transmitters are usually also equipped with short-wave and medium-wave telegraphy installations. This requires that for simultaneous operation the short-wave receivers must have a far higher standard of performance than the extremely simple receivers usually employed for ship work.

A receiver of the double detection type, with high-frequency selective circuits, has been adopted which will receive on frequencies separated by only about 1 per cent from that of a transmitter of considerable power situated on the ship, without any overloading due to the latter. Refinements have also become necessary on the long-wave telegraph transmitters to minimize key clicks, the effect of which the telephone receiver would be unable to eliminate, no matter how great its selectivity.

(*b*) *Aircraft Communication.*

Communication with aircraft in flight and the provision of navigational aids form one of the applications of radio which must necessarily be regarded as an essential service. During the year 1930 a total of 9 685 flights were made by commercial aircraft between Great Britain and the Continent, as compared, with an average of 7 573 during the previous 4 years, and as additional routes are opened further expansion may be contemplated. With the increase in commercial flying, expansion in the essential services of weather reports for assisting the navigation of civil aircraft using radio is taking place, and similar developments are going on in connection with military aircraft requirements. Aircraft transmitters are being improved in the direction of equipping independent drive circuits to provide frequency control, and in the use of 4-electrode valves for receivers.

Restrictions of space and weight and the question of liability to vibration seriously handicap the designer of aircraft radio sets. Interference from the ignition system is also a source of trouble, an effective cure for which has been shown to be complete screening of the ignition system itself.

Direction-Finding.—The use of screened loops on aircraft, in accordance with the practice in general use on ships for direction-finding, has been tried experimentally, but the limitation on the size of the loop it is possible to install—even on the largest flying-boat—reduces the pick-up and signal-level/noise-level ratio to impracticable limits.

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* R. H. Barfield: "Recent Developments in Direction-Finding Apparatus," *Journal I.E.E.*, 1930, vol. 68, p. 1052.

† Sir Thomas F. Purves: "The Ship-to-Shore Radiophone Service," *I.E.E. Students' Quarterly Journal*, 1930, vol. 1, p. 6.

Promising results have been obtained with what is known as the wing-coil "homing" method, wherein the currents in a single wing loop are combined through a reversing switch and suitable coupling unit with those induced in an open or trailing aerial with phasing resistance. This method seems to have a useful application as a simple navigational aid for commercial aircraft flying over long air routes such as those now being organized to the Cape and elsewhere.

Equi-Signal Beacon.—Much work has been done in America on the development of radio beacons giving a continuous indication of the course to the aircraft pilot.* By means of directive beams radiated from the airport, having modulations at two slightly separated frequencies, it is arranged that on the line of true bearing the rectified modulations are equal, whilst deviation from the course increases the one and decreases the other of the two rectified outputs. The tone frequencies operate tuned-reed indicators, and these are arranged to give a direct visual indication. A visual beacon of this type is now being installed at Croydon aerodrome for the assistance of navigators during periods of low visibility.

The Adcock direction-finder used at the ground station has been shown to have the same advantages for air work as for marine work, and to give a high order of accuracy on the wavelengths used for air direction-finding. The first installation of this type in this country is now being erected at Pulham for navigational assistance on the cross-channel routes.

Transmission of Line Drawings from Aircraft.—A simplified form of picture sender has been introduced, primarily for use in military aircraft, but it may have other applications.

The sketch or drawing is made with an "HB" pencil on specially-prepared paper. This paper is clipped on to a drum around which rotates a stylus. The passage of the stylus across the pencil lines causes the radio transmitter to be keyed. Reception is effected by the use of a chemically impregnated paper clipped on to a similar drum around which rotates a stylus connected to the output of the receiver. The passage of current from the point of the stylus through the damp paper to the drum, causes a chemical change and thus reproduces the original sketch. Synchronism is obtained by means of motors; the speed of the motor associated with the transmitter is maintained constant by means of a tuning fork, while the motor associated with the receiver is regulated by a valve oscillator-generator circuit.

An interesting example of the transmission of weather maps from a ground station occurred in connection with the preliminary flights of the R100 prior to her Canadian voyage. On this occasion the Fultograph process was employed, the transmissions being from the Rugby radio station, which was operated by remote control from Cardington where the weather maps were prepared.

FIXED SERVICES.

(*a*) *Telegraphy.*

Technically the chief developments in long-distance short-wave radio telegraphy have been in the direction of obtaining greater stability in the frequency of the transmitted carrier wave to minimize interference between services, and of improvements in aerial design to reduce the effects of fading.

It is now generally recognized that, in order to provide for all demands, the minimum essential width of band must be occupied by all services, and limits of tolerance of frequency have been agreed upon internationally.

To comply with the tolerances applicable for fixed services some form of controlled oscillator is essential, and for the higher frequencies those chiefly used are the valve master oscillator and the quartz crystal oscillator. An improved type of master-oscillator valve drive has been developed by Franklin in which automatic correction for temperature variation is obtained by the use of special materials in the tuning circuit, and by the use of a number of frequency-doubling and stabilizing stages between the master oscillator and the main amplifier. Very great improvements have also been effected in the quartz oscillator type of control—mainly by the use of thermostatically-controlled heated containers for the oscillator and by improved methods of selecting, grinding, and mounting the crystal.

(*b*) *Aerial Systems.*

There are at present in use a large number of types of aerial systems designed to confine the propagation within a small angle in the direction between the stations.*

In principle these mainly consist of various alternative means of combining numbers of half-wave or quarter-wave aerials appropriately spaced and in the correct phase relationship to reinforce in the required direction, with the corollary of neutralizing or partly neutralizing in other directions. The elements may be arranged horizontally, vertically, or, as in some types, diagonally.

A combination of two or three aerials at the receiving station, known as the "diversity" system of reception, has been found to reduce very substantially the quick fading effects which occur in the reception of telegraph signals.

For high-speed commercial circuits where the traffic is very heavy the combination of three aerial systems spaced from 10 to 20 wavelengths apart at the three corners of an equilateral triangle is of great value.

The expansion of long-distance radio telegraphy services has necessarily been affected in some measure by the merging of cable and wireless interests and the removal of the incentive to provide new wireless links in direct competition with cables. Another factor has been the peculiarly adverse magnetic conditions which have prevailed during the last two years. The correlation which has been established between transmission conditions and magnetic disturbances seems to indicate that, in addition to the severe interference with the propagation of short waves which occurs during magnetic storms, the optimum wavelength for effective transmission is definitely increased when magnetic storms are prevalent.*

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* F. W. DUNMORE: *United States Bureau of Standards Journal of Research*, 1928, vol. 1, p. 751.

* T. WALMSLEY: "Beam Arrays and Transmission Lines," *Journal I.E.E.*, 1931, vol. 69, p. 299.

The cycle of solar disturbance and magnetic storms having a periodicity of 11 years has just passed its maximum. Five or six years ago wavelengths of the order of 50 m gave excellent results between England and Canada at a time of the day when 20 m is now found to be necessary, and similar results are obtained on other services. It seems probable that, for the half cycle now being reached, a shift towards higher wavelengths will again be desirable.

(c) *Long-Distance Telephony.*

The first commercial long-distance radio-telephone circuit was that established in 1927 linking the British Post Office telephone system with that of the American Telegraph and Telephone Co.

This country has continued to take a leading part in the development of radio telephony, and four channels are now working from the Rugby and Baldock terminal stations of the Post Office to the U.S.A.; there are direct services also to Australia (with a radio extension to New Zealand), Canada, Buenos Aires (working alternately to two administrations), and Rio de Janeiro. Equipments for direct service to South Africa, Egypt, and India, are under construction, while a service to Japan is likely to mature in the near future. Telephone subscribers in this country are at the present time able to communicate with about 90 per cent of the world's telephones. An additional telephone circuit to the U.S.A. is now under construction which will utilize long waves. This will make five channels available in all—two long-wave and three short-wave—and will result in greater stability in the overall services particularly during magnetic storms, when although short waves are seriously affected, the long waves of the order of 6 000 m, which are employed on this service, give rather better than normal reception.

The reliability and number of effective hours of commercial working of long-distance radio-telephony services have been largely increased as a result of the technical improvements which have been effected since the first services were inaugurated. The following are the principal directions in which advances have been made.

(i) *Receiver Design.*—Improvements have been effected in overall gain and stability to meet the extreme conditions varying from weak signal strength and low signal/noise ratio, to those of high signal strength. Commercial operation is now possible under conditions when signal strengths may fall as low as 0·5 microvolt per metre. Overall gains of 130 decibels from high-frequency input to low-frequency output are obtainable in high-grade receivers. Automatic gain control is applied to cover variations of 60 decibels in the received fields, without distortion.

(ii) *Short-Wave Transmitters.*—In general the development has been on similar lines to that indicated for telegraph transmitters, but the power output is usually larger. The final amplifier stage for commercial services normally comprises four water-cooled metal-glass valves of from 10- to 15-kW high-frequency output with 80 to 100 per cent modulation.

(iii) *Single Side-Band System.*—A promising attempt to overcome the difficulties due to selective fading has recently been made by the experimental application of the single side-band system to short wavelengths. This system has the merit that in addition to reducing the bad effects of both synchronous and selective fading it improves the tramsmission efficiency and also reduces the band width by one-half. The single side-band principle has been successfully used for some years on the long-wave transatlantic telephone circuit. The difficulty encountered in applying it to short wavelengths is that of re-supplying the carrier at the receiver at exactly the right frequency. The precision required on a wavelength of 15 m is at least 1 part in 10^6.

In the short-wave system referred to, the method adopted for re-supplying the carrier is the use of a local oscillator at the receiver automatically stabilized by a pilot signal transmitted at the same time as the side band. The pilot signal used has a continuous wave corresponding to a speech frequency of 3·4 kilocycles per sec. and is transmitted at a level 20 decibels below the peak value of the side band. A very sharp filter is used for selecting the pilot signal, which, in spite of its reduced level, attains a signal/noise ratio about equal to that for the speech itself. The local carrier is still present should there be complete fading of the pilot signal, and the circuit is arranged by means of a time-constant to prevent the frequency of the local oscillator from changing by more than 20 cycles per sec. in the complete absence of the pilot signal over short periods.

The receiver is of the triple detection type, the two intermediate frequencies being 500 and 20 kilocycles per sec. respectively. The first beating oscillator is controlled by a quartz crystal and the second by the pilot signal. Two automatic gain controls are used; one is of very short time-constant and is for the pilot channel only, the other has a time-constant of the order of 30 sec. and operates on the first detector.

The transmitter is an adaptation of the usual low-power modulation type. The single side band is obtained by modulation in three successive stages. The first two are at 19 and 250 kilocycles respectively, the modulators being balanced and the side band selected by filters. The third modulator is not balanced, a sufficient suppression of the carrier and the unwanted side band being obtained by sharply-tuned circuits in the rest of the transmitter.

(iv) *Single-Wavelength Systems.*—Commercial duplex or 2-way telephony, as distinct from broadcasting, normally employs two frequencies at any time—one for each transmitter. An exception is the long-wave transatlantic telephone channel, which was designed to operate on a mid-wavelength of 5 000 m in each direction. This is achieved by arranging that the transmitters are normally quiescent and radiate only when the initial pulse of speech arrives and removes a bias potential from the control grid circuit.

For telephony on board ship the desirability of suppressing the carrier wave has already been discussed, and the adoption of a single wavelength for operation in both directions is a comparatively simple step forward. The arrangement has been successfully tried on the telephony installation of the s.s. "Olympic." The adoption of the single-wavelength system for point-to-point services would help to solve the problem of finding space for additional services in the congested portions of the frequency spectrum.

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* C. E. Rickard: *Journal I.E.E.*, 1931, vol. 69, p. 11.

(*d*) *High-Tension Supply for Radio Transmitters.*

An interesting development in recent high-power transmitter equipment is the use of Brown-Boveri mercury-steel arc rectifiers for high-tension direct current. These rectifiers operate with outputs up to 500 kW at voltages of 15 000 volts or higher, and compare favourably in efficiency with thermionic diodes.

Water-cooled rectifiers of the normal diode type have been developed up to output powers of 3 amps. at 20 000 volts. Direct-current generators are still being used for many new installations. The high-tension d.c. machines at the B.B.C. regional stations are rated at 160 kW at 12 000 volts, and a new d.c. machine at Rugby develops 500 kW at 12 000 volts. The mercury-vapour hot-cathode rectifier is also being used for high-tension supplies, and is a promising competitor. The largest units of this type are capable of delivering 25 kW of rectified power and of withstanding a back pressure of 40 000 volts.

(*e*) *Transmitting Valves.*

The increase of the power employed in transmitters has led naturally to the development of valves of larger power to reduce the number of valves required in the final amplifier stages. Typical examples of recent developments are water-cooled triodes of 50-kW anode dissipation operating at 15 000 to 18 000 volts, rated at 100 kW; and 120-kW valves for a plate voltage of 20 000 volts. A demountable continuously-evacuated valve rated at 500 kW recently produced in this country is the largest single unit now in operation, and it has shown great possibilities of development.*

TELEVISION.

Many systems of television are in operation in different countries on an experimental basis, and in this country transmissions on the Baird system are now regularly broadcast from the London Regional station for short periods. Attention has been concentrated on the major problems of (*a*) providing the very wide frequency band which is required for even a moderately detailed reproduction; (*b*) providing sufficient illumination on the receiver screen for a number of people to view the image; and (*c*) improving synchronization. While the scientific interest of the systems at present in use is beyond question, their entertainment value is perhaps doubtful.

Amongst interesting developments are the use of the cathode-ray tube for the reproduction at the receiver, the image being produced on the fluorescent screen by the scanning of the electron rays. The absence of inertia in this device and the persistence of vision due to the fluorescent screen are among its important advantages. This process is being adopted largely in America. The use of a number of channels between transmitter and receiver each of which deals with a portion of the frequency band required for the picture signals is another promising development. The difficulties appear to centre around the alignment of the separate channels on the screen to avoid overlapping and the consequent objectionable flicker and mutilation of the picture. The important requirement of equal amplification on all the channels is also difficult to meet.

With few exceptions the recently inaugurated experimental television services are being operated on short waves. The band width essential to give adequate reproduction is of the order of 600 000 cycles per sec. It is therefore clear that the ultimate exploitation of television by radio will be in the higher-frequency parts of the spectrum.

BROADCASTING.

(*a*) *Regional Scheme.*

The regional scheme of broadcast distribution has progressed according to plan. The London Regional and North Regional stations are in operation on a dual-programme basis, the Scottish Regional station is being constructed at Falkirk and the site for the Western Regional station has been purchased at Washford Cross, near Watchet, Somerset. The latter station is intended primarily to serve the South Wales district, and it is interesting to note that as the result of investigation as to the attenuation of waves of the order of 300 m when propagated over sea as compared with land it was found that by choosing the site on the southern shore of the Bristol Channel a considerably higher and more even distribution of field intensity could be given to South Wales and the Bristol Channel than by locating the station in South Wales.

(*b*) *Power of Stations and Interference.*

There has been a general tendency to increase the power of broadcasting stations, and there are now in Europe some 30 transmitters already working or in course of construction having a carrier-wave power in the aerial of 50 kW or more. The maximum power (120-kW carrier wave) is at present used by Warsaw and Prague.

The agreed spacing between stations was fixed in the Prague Plan of 1929 as 9 kilocycles per sec. At that time there were four medium-wavelength high-power stations, and the only interference due to the neighbouring station was a heterodyne note between the carrier waves of 9 kilocycles per sec. which was unnoticeable in the majority of receivers. The growth of the power used by the stations has accentuated the interference due to carrier heterodyning and that due to the side bands of the unwanted station being impressed on the carrier wave of the wanted station.

This problem of interference has been investigated by the B.B.C. and the Union Internationale de Radio Diffusion (U.I.R.). The results of the experiments may be summarized as follows:—" In the case of a station capable of radiating a given power, firstly using a wave in the medium-wave band—say 300 m—and, secondly, using a wave in the so-called ' long ' wave band—say 1 600 m—the maximum signal strength produced by indirect ray at night, at a distance of 300 to 500 miles, would be some 5 times greater in the case of the shorter wave. The ratio of maximum night value to steady day value at the same distance would be some hundreds to one in the case of the 300-m wave, whereas for the 1 600-m wave it would be of the order of only 3 or 4 to 1. It was found that most transmitters of 50-kW carrier-wave power produced peak values of field intensity up to 5 mV per metre at distances of 600 miles or more during the hours of darkness."

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* *Journal I.E.E.*, 1932, vol. 70, p. 33.

The B.B.C. has conducted a number of experiments based on these figures, using normal commercial broadcast receivers, and the results indicate that if the separation between stations is increased from 9 to 11 kilocycles per sec. the improvement is such that the ratio of local-field to interfering-field intensity can be about halved to give the same (just audible) interference.

(*c*) *Synchronized Transmitters.*

An economy of wavelength channels has been achieved in this country by the use of "synchronized" transmitters. At the present time seven relay transmitters are working together on the British exclusive wave of 1 040 kilocycles per sec. (288·5 m). These transmitters are synchronized by means of tuning forks, each station being provided with its own fork, the frequency of which is maintained constant by thermostatic control of temperature. The method of bi-weekly check of the seven forks is interesting. A similar type of fork, whose frequency is approximately 1 015 cycles per sec., is kept working under thermostatic temperature control at the B.B.C. research laboratories. This fork drives a synchronous-motor clock, which allows the actual frequency of the fork to be checked against Greenwich mean time, as provided by the B.B.C. time signals, every 24 hours. Any necessary adjustment of temperature to give this fork its desired frequency within small limits is made. The output of this fork is quadrupled in frequency by two frequency-doubling stages, similar to those installed at the relay transmitters themselves, and the resultant 4 062·5-cycle note is sent by line to Daventry 5XX where it is caused to modulate this transmitter. The relay stations receive Daventry 5XX on their Daventry relaying receivers, and compare the frequency of the fourth multiple of their own forks with the frequency of the received modulation from Daventry by the beat method. Any necessary slight adjustments of frequency can then be made to their own forks.

(*d*) *Studio Acoustics.*

One of the most important features necessary to ensure satisfactory broadcast transmission lies in the acoustical problems encountered in studio design. In the past two years considerable new work has been undertaken by the B.B.C. on this subject, particularly with a view to the design and construction of the studios in its new headquarters at Langham Place.*

The first consideration was to ensure that no spurious sound should reach the studios at an audible level. It is usually considered to be satisfactory if such sounds can be kept down to a level corresponding to 50 to 60 decibels below the music level. Most modern buildings of considerable size are built on the steel-frame principle, and, in these circumstances, the danger of transmission of sound from one part of the building to another is considerable. It appeared necessary, therefore, that in a new building intended to house several studios, continuous steel-frame construction should be avoided. Thus in the new B.B.C. building at Langham Place the studios are contained in the central portion of the building, the walls of which are constructed mainly of brick; steel girders are used only in the lower portion, and not in such a way as to cause transmission of sound from one studio to another.

Special precautions were taken to prevent the transmission of spurious noise from one studio to another through the medium of the ventilating plant, and the desired result was obtained by supplying separate plant for each studio. Precautions were also taken to prevent noise from the blowers from reaching the studios by the air ducts. This was effected by reducing to a minimum the noise made by the blowers themselves, and by lining the ducts with sound-absorbing material and dividing up the cross-section of the duct by longitudinal baffles, also constructed of sound-absorbing material. Apart from the question of sound insulation, great importance was attached to measures for ensuring that the walls, floor and ceiling of the studios should be absolutely rigid and exhibit no tendency to act as a flexible diaphragm under the influence of sound waves.

(*e*) *Blattnerphone.*

The last two years have seen a very great development in the art of sound recording. Methods for recording sounds on film and on wax are prominently before the public, and for cheapness, reliability and good quality of reproduction, present-day gramophone records attain a high standard. The gramophone has been adopted in Germany for use in broadcasting, particularly at rehearsals, but in this country a lesser-known system—i.e. recording on steel tape—has been developed. The apparatus for this purpose, known as the "Blattnerphone," has received considerable development at the hands of the B.B.C. and as now used by them it gives a quality of reproduction in every way comparable with that of the best gramophone records. In the present machine a tape speed of 1·2 m per sec. is used and a playing time of 17 minutes is given. This is only limited, of course, by the length of tape at present contained on the reels. Experience regarding the effects of time is necessarily limited, but there is as yet no evidence that the record is not permanent or that it is worn by repeated replaying. The tape can be cut and joined again just as is done in film reproduction, if a composite programme is required.

(*f*) *Long-Distance Relays.*

For line relaying in this country, the system is gradually being changed over from overhead-line distribution to underground cable circuits. At the present time in these circuits a frequency gamut of approximately 50 to 6 000 cycles per sec. is assured, but for newly-laid cable circuits equalization will be possible up to 8 000 cycles. Similarly in Europe a system of special circuits has been built up which can now be used for international relaying of musical programmes. In the domain of linking land line to radio, increasing use is being made of the transatlantic radio-telephone service, especially by the two large American broadcasting chains, for the transmission in America of European broadcast programmes.

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* N. Ashbridge: "The Acoustical Problems of Broadcasting Studios," *Engineering*, 1931, vol. 132, pp. 481 and 511.

No review of broadcasting would be complete without a mention of the world-wide broadcast by His Majesty the King, which took place at 11 a.m. on Tuesday, 21st January, 1930, when he opened the London Naval Conference. Every possible type of link was used for this broadcast, and a total of 242 broadcast transmitters were simultaneously radiating the programme—112 in Europe and 130 in the rest of the world; indeed a truly international relay!

(*g*) *Broadcast Receiver Design.*

Two factors which have influenced the direction of development in the listener's set have been the increase in the number of broadcasting stations and the higher power used, which have made it necessary to improve the standard of selectivity in the receiver.

The use of band-pass filter circuits has offered one solution which is capable of much further application. The super-heterodyne set using screen-grid valves with high-frequency amplification followed by an intermediate-frequency amplifier and finally a low-frequency amplifying stage is one very satisfactory type which is largely used.

The general adoption of "all mains" sets, eliminating the use of batteries, is a notable advance which has become possible as the result of the improvements in indirectly heated valves and in smoothing circuits. This means of eliminating batteries is applied throughout the range, from the 2-valve set for loud-speaker reception of the local-station programme to the multi-valve long-distance receiver. Indirectly-heated valves have now been commercially produced for normal d.c. voltages as well as for a.c. mains operation.

Ultra-Short Waves.

A considerable amount of work has been carried out in exploring the possibilities of ultra-short waves. The propagation of these waves is not assisted by the upper atmosphere and they have therefore a limited range. There appear to be definite possibilities of their application to short-distance communications between aircraft in flight, aircraft to ground and vice versa, and between portable sets on the ground. Under suitable conditions for short-distance point-to-point telephony over water they compete commercially with cables and have been applied to link up islands with the mainland telephone systems.

The lower limit of wavelength adopted for commercial application so far is about 3 m, but the possibilities of the use of still higher frequencies have been demonstrated.

A 2-way telephone circuit which presents many striking features has been tried out between Dover and Calais using wavelengths below 20 cm.* The extremely short wavelengths enable a parabolic transmitting and receiving system to be used of dimensions comparable with those employed for optical purposes. The radiated waves are concentrated into a very small solid angle accurately directed towards the receiver, so producing a gain of the order of 50 decibels and giving a sufficiently high field for telephony with a radiated power of the order of 0·5 watt.

Research and Measurements.

Research work on many of the fundamental problems connected with the propagation of radio, the study of atmospherics, etc., has made notable advances, and in this connection particular reference should be made to the investigations undertaken by the Radio Research Board.* Great progress has been made in the technique of measurement of electrical quantities at high frequencies. The more precise quantitative knowledge that it has brought has had a greater influence perhaps than any other factor on the design of apparatus and the consequent improvements in its efficiency.

(*a*) *Field-Strength Measurements.*

Commercial apparatus has been produced for the measurement of field strengths within a range of from 14 m to the longest wavelengths in use, and capable of recording values as low as 1 microvolt per metre. The statistical data which have been obtained from field-strength observations of numbers of commercial stations have made it possible to predict the behaviour of new services with increasing accuracy. Field-strength measurements have also been applied to the verification of polar diagrams of directive array systems and have established valuable correlation with theoretical calculations.

(*b*) *Frequency Measurement.*

The standard of accuracy of frequency measurement now obtainable is of the order of 1 part in a million for low frequencies. Observation stations equipped with suitable apparatus can measure the frequency of transmitters working on the short-wave ranges to an accuracy of at least 1 part in 50 000. Laboratory measurements on these frequencies can be made to within 1 or 2 parts in a million. This development has been necessary and has contributed to the advances which have been made in the stabilization of frequency of transmitters.

(*c*) *Power Factor and Permittivity.*

The uncertainty of the behaviour of insulating materials at high frequency and their high losses and liability to breakdown at comparatively low voltages have been one of the problems in radio engineering to the solution of which little precise information was available. This difficulty has been met, and high-frequency bridges are now available which are capable of giving reliable measurements at moderately high frequencies. For the very high frequencies, however, much research still remains to be done.

(*d*) *Reflection Phenomena.*

Investigation and experiment have produced precise knowledge of the absolute reflection coefficient of the ionized layer in the atmosphere and its variation with the angle of incidence of the transmitted rays. Direct application of these measurements has been made in the prediction of the service areas of broadcasting stations.

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* *Electrician*, 1931, vol. 106, p. 509.

* Report of the Radio Research Board for the Period Ended 31st Dec., 1930. (H.M. Stationery Office.)

(e) *Cathode-Ray Oscillograph.*

The oscillograph of the type developed by von Ardenne has proved an invaluable instrument for the study of atmospherics and has made possible the photography of their wave-form. The photographic process of facsimile recording, with the use of high modulation frequency, has also contributed to an increase of knowledge of reflection effects in long-distance transmissions. Precise means of measuring echo intervals and examining reflection phenomena are obtainable from these records.

(f) *Current Measurements at Very High Frequencies.*

The uncertainty of the current measurements involved at the higher frequencies now in use for commercial radio telegraphy and telephony has directed attention to the design of ammeters for which correction factors may be calculated with certainty. Two such types of instruments intended for use up to frequencies of 100 million have recently been described.*

In the exploitation of both radio telephony and radio telegraphy and the production of equipment this country is well in the forefront. The empire and international radio-telephony services from this country are centred in the British Post Office administration and are thus linked directly with the internal telephone system under the same control. The point-to-point radio-telegraph services with a few exceptions are operated by Imperial and International Communications, Ltd., and thus are now merged with the cable systems operated by the same organization, giving a very complete network of world-wide extent.

No review of radio progress would be complete without reference to the developments which have been made by Marconi's Wireless Telegraph Co., Ltd., Standard Telephones and Cables, Ltd., and the British Broadcasting Corporation, who have supplied the author with much valuable information.

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* C. L. FORTESCUE: "An Ammeter for Very High Frequencies," *Journal I.E.E.*, 1930, vol. 68, p. 556; also E. B. MOULLIN: "The Development of a Precision Ammeter for Very High Frequences," *ibid.*, 1930, vol. 68, p. 544.

TELEGRAPHY AND TELEPHONY, 1929–31.*

By W. CRUICKSHANK, Member.

Following the practice adopted in the two preceding reviews,† Table 1 shows the wire mileage existing in this country at the periods under review.

TABLE 1.

	31st March, 1925	31st March, 1928	1st March, 1931
	miles	miles	miles
Total single-wire (working and spare)	5 222 424	7 528 641	9 404 439
Telegraph (working)	273 010	298 361	320 589
Telephone (working)	4 387 324	6 310 317	8 150 452
Telephone trunk lines (working)	669 753	890 215	1 112 128
Telephone local exchange lines (working)	3 717 571	5 420 102	7 038 324

Subdividing the lines, as before, into four classes—aerial, underground, submarine, and spare—the figures are as shown in Table 2.

TABLE 2.

	1925	1928	1931
	miles	miles	miles
Aerial wire (working)	1 068 545	1 178 693	1 309 766
Underground wire (working)	3 573 064	5 408 192	7 144 975
Submarine wire (working)	19 725	21 793	16 300
Spare wire	562 090	919 963	933 398
Total	5 222 424	7 528 641	9 404 439

In the period 1928–31 the wire mileage has increased by just under 25 per cent, as against 44 per cent in the previous three years. The decrease in the submarine mileage is due to the sale of the two transatlantic cables (7 370 miles) to Imperial and International Communications, Ltd.

It may be of interest to quote (see Table 3) the mileage figures of the American Telephone and Telegraph Co. for the two periods ending 31st December, 1925, and 31st December, 1930, which are comparable with the above.

The increase over the 5 years is some 68 per cent. The British Post Office system, with, of course, a much smaller mileage, shows an increase of 80 per cent over practically the same period. Attention is directed to the enormous increase of toll-line (trunk) mileage in the United States during the 5 years, some 5 000 miles of toll cable having been added in 1930, each cable carrying many circuits. There are now 129 cities having populations of over 50 000 inhabitants connected directly to the Bell trunk network. The distance between cities and consequent cost of line plant in America and Australia has contributed to the great development in those countries of carrier-current working on physical pairs, the system being used for both telegraph and telephone transmis-

TABLE 3.

	1925	1930
	miles	miles
Toll Line (Trunks)		
Underground cable ..	2 057 000	5 769 000
Aerial cable	1 210 000	4 576 000
Open wire	2 366 000	3 036 000
Total	5 633 000	13 381 000
Exchange Wires		
Underground cable ..	28 426 000	44 456 000
Aerial cable	9 462 000	16 209 000
Open wire	1 953 000	2 202 000
Total	39 841 000	62 867 000
Total miles of wire ..	45 474 000	76 248 000

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* A review of progress. Reprints in pamphlet form, price 1s. each, can be obtained from the Secretary of the Institution.

† *Journal I.E.E.*, 1926, vol. 64, p. 154; and 1929, vol. 67, p. 176.

sion. An instance is quoted in the 1930 Annual Report of the American Committee on Communications, of a pair of wires accommodating a duplex d.c. telegraph circuit, an ordinary 2-way message telephone circuit, and 36 duplex carrier telegraph channels. Further details of the Australian developments are given later in this review.

Part 1: TELEGRAPHY.

INLAND TELEGRAPHS.

In the face of an adverse balance and continuously falling traffic, an administration might be pardoned if it slowed-down and waited for the inevitable end of things. Such, however, is not the attitude of the British Post Office administration, which is at present probably engaged upon more technical studies and trials than were ever before on foot at the same time.

The extension of concentrator working has continued, both in the Central Telegraph Office and in the provinces. Phonogram working, i.e. the sending of telegrams by telephone subscribers to the nearest important office, has been elaborated, and in many districts subscribers now send their telegrams direct to phonogram operators in large centres, a practice which reduces the number of retransmissions and saves delay. Some difficulty is occasioned until the users become acquainted with phonogram methods, and care is being taken to ensure that good-class telephone sets are used for the purpose and that the line attenuation is not too great. Telephone communication by speech can be carried on successfully under difficult conditions if there is a mutual understanding between the two communicants, but errors may creep in when a user is dictating a message to an operator who has no initial understanding of the tenor of the contents. Fundamentally, a telegram can be more accurately transmitted when the words are spelt out letter by letter. The danger of error is reduced by the use of the phonetic symbols for letters, which army service taught to so many and of which an example remains enshrined in the name "Toc H."

The teleprinter system continues to supersede Baudot and Morse working on important routes. Well over 1 000 instruments of the No. 3A type, which were developed and are being manufactured by Messrs. Creed at Croydon, are in use on the circuits, with an adequate number of spare sets in reserve to replace instruments that develop faults while in operation. The circuits are jack-wired and the sets are fitted with a plug and flexible cord, so that the replacement of an instrument is only a matter of seconds. About 50 per cent of the early instrument faults were due to the anchor escapement, which in the first machines was linked between the tongue of the electromagnet and the trip shaft, which in turn makes the selections forming the letters. This escapement, which was known as the "mechanical relay" or "relay engine," is eliminated in new sets, and is being removed from instruments under repair. An extension piece from the electromagnet tongue now operates the trip shaft direct without the interposition of an escapement, and much better results are being obtained. Trouble was also experienced with a.c. motors supplied with sets to be used at places where the electric power supply is alternating. To this 110-volt d.c. motors have been standardiz the a.c. supply will be rectified by copper-oxide re Local-circuit currents, and in some cases line c also, will be derived from the rectifiers.

The use of teleprinters for special events such meetings, political addresses, etc., is being int more extensively, and "pooling" sets specially w baseboards will be held at certain local centre issued for immediate use when occasion dema teleprinter concentrator has been designed and i at Scotland Yard to provide teleprinter commu between headquarters and six selected police s either simultaneously, singly or in two group separate machines. The police stations can comm with Scotland Yard in either direction; their tel motors are switched on by signals from headqua that personal attendance is not necessary.

Systems of this type have been introduced ext in the United States. In addition to the sta police teleprinter systems in Connecticut and I vania, an elaborate network of about 30 stati installed last year in New Jersey. New Yo Boston, Buffalo, and St. Louis also have extens works operated on teleprinters (or "teletypew as they are called in America) by the police ther

The development of underground networks ha Department to consider the possibility of letting hire at reduced rates what may be called th products" of the networks, for the use of the p private wires. The introduction of telegraph into telephone underground cables is not new, b d.c. methods are employed special precautions taken to prevent "cross-fire" by utilizing the E the pair as an earthed screen, by the use of sm filters, and by keeping the working currents do minimum. Experimental sets are now being operate with alternating current on the cables, supply being generated either at the repeater at the cable ends, or by oscillators, or multiplie supply frequency at the renter's premises. The used on the lines will be of the same order of a as telephone currents, the frequency being kep neighbourhood of 300 so as to be within the ran telephone repeaters yet below that of high-fr ringing (500 cycles per sec.), to avoid disturba that source. Circuits will be provided for h transmission by the reservation of a single pai can be used either for teleprinting or speech provision of phantoms on multiple-twin and s cables, by super-phantoms on quads, or by channels of a multi-frequency arrangement o Amplifying and rectifying valves will be use receiving ends, which will be made up in sets s the "all-mains" broadcast receivers. There w talk of the establishment of teleprinter exch London and the larger cities, but the necessity has probably been obviated by the production o and receiving systems which can be used on subscribers' lines and brought into operation by a switch to change over from speech to teleprin

Several d.c. circuits have been superposed on telephone phantoms, one of the most interestin

London–Glasgow circuit which is carried on the main backbone trunk route, the distance being some 400 miles. The advantage of this super-phantom circuit is that it can be carried on telephone circuits which are fitted with repeaters, but the telegraph currents by-pass the repeaters.* Composite circuits carrying telegraphs have to be fitted with low-pass filter by-paths to enable the telegraph signals to pass the repeaters, but the super-phantom arrangement is simpler. At the repeater stations each physical circuit terminates on an input transformer, the secondary of which is connected to the grid of the circuit valve. The telephone phantom circuit is connected to taps in the centres of the two side-circuit transformer primaries and between these taps is connected the phantom transformer, the secondary of which is joined to the grid of the phantom repeater valve. Now, by picking up a tap on the centre of the primary of the phantom transformer a lead can be run to the corresponding point on the output side, so that the telegraph d.c. currents are shunted right round the repeaters. The importance of this is appreciated when the number of repeaters on the London–Glasgow route is considered. Repeaters are fitted at the London Trunk Exchange, at Fenny Stratford, Derby, Leeds, Catterick, Newcastle-on-Tyne, Jedburgh, Edinburgh, and at the Glasgow Trunk Exchange, 9 each way. The "go" circuit is not earthed at Glasgow, but is connected to a similar "return" quad which is earthed at London. When first installed, there was very little margin on the circuit and it was suggested that loading should be tried. The only places where coils could be inserted without opening the cable were at the repeater stations, roughly 50 miles apart, and the obvious point for the coil was in the tap lead connecting the input to the output phantom transformers. Loading coils were inserted at these points and a much better working condition was secured. Vibrating relays were dispensed with, the receiving-relay coils being shunted by an inductance in series with a resistance—the well-known magnetic shunt used with submarine receivers. Teleprinters are worked in the local circuits, the receiving relays being operated with 5-mA currents (approximately 1 mA per wire). The teleprinter frequency was taken as 25 for calculation purposes, and with the spacing fixed by the position of the repeater stations the loading per section was found to be of the order of 15 henrys. This value varies with the length of the section, the inductance of the coils ranging from 11 henrys at Derby to 16 at Catterick and Edinburgh. Half-value coils are fitted at the terminals. The ratio R/L of the coils is about 10. Laboratory tests indicate that the circuit could be extended to 600 miles.

An important departure from Post Office telegraph practice in the past has been carried out at Leeds and will probably be extended to other large offices. All apparatus not required in the actual manipulation of the sets has been removed from the instrument tables and mounted on a suite of racks at the end of the instrument room. The racks at Leeds provide for 48 teleprinter duplex and 5 Morse simplex circuits. A battery switch to allow the line voltage to be changed as required, a teleprinter test circuit, and relay test and concentrator panels, are associated with the racks.

VOICE-FREQUENCY AND CARRIER TELEGRAPHS.

Two double sets of 6-channel voice-frequency telegraphs are in operation in this country, one between London and Manchester, the other between London and Glasgow. The former was built by Messrs. Siemens and Halske, and the latter by the telephone works of the General Electric Co. at Stoke, Coventry. The service given by these sets is fairly satisfactory. Teleprinter and Morse are used on the channels; one of the latter was originally extended at Manchester to Bolton, but the six now work to Manchester, and two Glasgow channels are extended to the Glasgow Stock Exchange. An interesting experiment was carried out last year in which the General Electric Co. apparatus at London was connected through to that of the S.E.L.T.* in Paris, and the possibility of inter-communication between the systems was demonstrated.

In Germany this system is being very extensively used on the departmental underground telephone cable network, while in the United States 400 000 additional channel-miles were installed during the year 1930.

Important developments in this direction have taken place in Australia, a country pre-eminently suitable for carrier work. Between Port Augusta (north of Adelaide) and Kalgoorlie (W. Australia) lies a stretch of 1 600 miles, barren, treeless and practically uninhabited. The transcontinental railway crosses this area, and along the route runs a telegraph line carrying three telegraph physical circuits. Two of these were worked Wheatstone duplex, with Creed printers, by the administration, and the third was rented to the Eastern Extension and China Telegraph Co. for connecting its Adelaide office with the submarine cable landing at Cottesloe, near Perth. Duplex repeaters were fitted at Port Augusta, Cook, and Kalgoorlie. On this route there have now been installed 8 duplex carrier channels, capable of extension to 10. One group of frequencies, from 3 330 to 5 500, is used in one direction, while another group, from 6 500 to 10 000, is used in the opposite direction. Direct multiplex systems are provided between Perth and Adelaide, Perth and Melbourne, and Perth and Sydney. The Perth–Adelaide link consists of a quadruple-duplex Murray system working at 45 words per minute per arm. The links Perth–Melbourne and Perth–Sydney are Murray triple-duplex systems also operating at 45 words per minute per arm, the latter working through rotary regenerative repeaters at Adelaide. One channel of the Perth–Adelaide carrier system is used by the Eastern Extension Co., who operate over it a Wheatstone-Creed system linking up with their cable at Cottesloe. The system installed is that of the Standard Telephones and Cables, Ltd., and was manufactured in England.

This company has developed a 12-channel voice-frequency set suitable for inland use in this country; it is very economical of current and occupies less floor space than the existing 6-channel sets now in use. The system has been demonstrated successfully over underground lines fitted with repeaters.

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* Société d'Études pour Liaisons Téléphoniques et Télégraphiques à Longue Distance.

PICTURE TELEGRAPHY.

The Siemens-Carolus-Telefunken picture transmission system installed in the G.P.O. West station and described in the last review is still functioning on public service and its range has been considerably increased. Public transmission service is open to Berlin, Frankfurt-on-Main, Munich, Vienna, Copenhagen, and Stockholm. In addition to the public service, a private service to the *New York Times* office in Paris and the *Hamburger Fremdenblatt* office at Hamburg is in operation.

There are now in Germany three public picture stations having a direct service with London and they cover the following areas approximately:—

Berlin.—Northern and eastern parts of Germany up to a line including Bremen–Hanover and Halle–Chemnitz.

Munich.—Southern Germany up to and including a line Stuttgart–Chemnitz.

Frankfurt-on-Main.—Remainder of Germany. Arrangements providing for direct picture transmission to the private offices of the *Seneri* and *Ullstein* publishing houses in Berlin were completed last year. A picture service between Germany and the U.S.A. via London was opened on the 18th November, 1930, and a similar service between Austria and the U.S.A. on the 1st February, 1931. Transmissions from Germany and Austria are received by the picture apparatus in London and positive prints are handed to Imperial and International Communications, Ltd., for retransmission by radio to America. In the reverse direction, positive prints received from Imperial and International Communications, Ltd., are retransmitted from London at the official picture station.

Most of the newspapers with printing establishments in London and provincial cities now have picture sets of the Siemens-Carolus, Bell or Belin types in operation over their private wires rented from the Department. The service is very good, close examination being required to detect the received print from the original. Its value in transmitting intricate financial sheets and tables is very considerable.

SUBMARINE TELEGRAPHY.

As mentioned earlier in this report, Imperial and International Communications, Ltd., have taken over from the Department the two transatlantic cables formerly known as "Imperial, Nos. 1 and 2."

A super-phantom telegraph circuit on the same lines as the London–Glasgow circuit described on page 155 has been installed for emergency working between London and Antwerp. Two loops, one for sending and one for receiving, were formed by superposing each on two telephone phantom circuits in the London–Canterbury–La Panne (1926) cable. The circuit carried triple Baudot signals and was worked successfully with 6 volts at each end. Experiments are being carried out with the object of replacing Hughes by teleprinter working between Liverpool and Rotterdam. Successful results were obtained duplex between London and Rotterdam. At the moment, high-frequency carrier trials are in progress on the Anglo-Dutch No. 3 cable. Telephone channels using this method have already been successfully demonstrated, as mentioned later. Trials have also been made on the Blackpool–Isle-of-Man telephone cable with the object of securing emergency telegraph channels to the Island and to Northern Ireland. The trials proved that excellent Wheatstone signals at 120 words per minute simplex could be transmitted over double superposed loops without causing interference to the working telephone circuits, using d.c. currents of a steady value not exceeding 5 mA.

Imperial and International Communications, Ltd., have recently introduced a new form of valve amplifier which has replaced the Heurtley magnifier for reception on long submarine cables. The receiving coil, suspended in a powerful magnetic field, is fitted with a light aluminium pallet which is fed from a thermionic-valve oscillator at 30 000 cycles per second. On either side of the pallet are fixed plates which are wired respectively to the grids of two amplifier-rectifier valves, the "dot" and the "dash" valves. There is thus a flexible electrostatic capacitance coupling between the pallet and the grids. As the coil is operated by the incoming signals these capacitances are varied and consequently the outputs of the two valves vary. In the output of the amplifier is connected a gold-wire relay, the coil of which carries a pair of fine gold wires which normally make contact with a pair of silver butts. The butts are automatically swivelled to the right or left by the regenerative retransmitting apparatus, to counteract the effects of the wandering zero produced by varying earth currents. Signals cause the gold wires to break contact with the butts and thus control local circuits. The suspended coil also carries a small mirror which reflects a beam of light on to a scale fitted above. This arrangement is particularly useful in securing a balance for duplex, as the movements of the coil are considerably magnified on the scale.

A combined form of synchronizer and retransmitter is used in certain cases in place of separate synchronizers and interpolators, the latter being employed in this company's regenerative-repeater apparatus to reshape the signals and to break up a run of dots or dashes, which come from the cable practically continuously, into their proper length as sent originally by the sending-end transmitter. As in the earlier apparatus, the instrument is driven by a clock-controlled phonic motor, which in turn is controlled by the incoming signals. The retransmitting is done by signalling levers which are locked and unlocked by continuously-revolving cams. One cam is adjustable to give any length of signal, and the levers can be rotated bodily about the cams so that the middle of the incoming signal, which is least affected by distortion, may control the operation of the levers.

A most ingenious call device for repeater stations has also been recently introduced by this company, by which the use of any section of long cable can be controlled entirely from London. Each repeater station along the route is fitted with a distinctive calling arrangement consisting of two ratchet-and-pawl adding-mechanisms. By sending a given number of dots a lamp is lit and a bell rings at the repeater station required. When the dash mechanism is operated similarly, automatic perforators come into operation and the retransmission of signals beyond that station ceases until the dot sequence is again used. By this means the cable can be broken at any station, and a batch of messages for that station can be perforated there. Beyond the station, work on the cable can proceed uninterruptedly.

Imperial and International Communications, Ltd., now work direct from London to Adelaide without hand retransmission.

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PART 2: TELEPHONY.

PROGRESS IN LONDON.

Steady progress has been made with the conversion of the London telephone area to automatic working, and some 35 automatic exchanges are now in full operation. New buildings have had to be provided for these exchanges, and since all the work has been executed through the intermedium of the Office of Works the architecture is distinctive but the buildings are not without a certain pleasing character. Heavy concentrated loads have to be carried by the floors, and reinforced concrete has been used largely throughout. An important building project is being carried out at Queen Victoria Street, where provision is being made to house a repeater station and equipment for trunk and toll circuits and two local automatic exchanges. The foundations have been carried down to the London clay stratum and very considerable shoring-up of the adjacent foot- and road-ways has had to be engineered.

Although the dialling of seven digits correctly proves a somewhat lengthy process, the public have taken to the system remarkably well and complaints of wrong numbers, etc., are becoming fewer. The groups of directors, switches, selectors and junctions are automatically routine-tested periodically, and thus faults—which are bound to appear in intricate mechanisms carrying thousands of electrical contacts—are located and cleared before trouble arises. In the process of conversion many intricacies have been removed and improved, operating methods are being introduced which will result in substantial economies being effected without loss of efficiency. One of the most interesting, both from the electrical and from the operating point of view, is the method that has been evolved for signalling and setting-up calls for automatic exchanges which originate in manual exchanges. The original scheme provided for the installation of cordless B positions at automatic exchanges, at which operators whose headgear sets were connected to the receiving ends of order-wires from manual exchanges, assigned the juctions to be used and, when the proper junction had been taken by the A operator, key-sent the required number (which was obtained by order wire) on a strip of 10 (plus 1 cancel) lightly-operated press keys. The four digits of the subscriber's number were stored on relay sets which finally selected the required subscriber's line. It was considered, and rightly so, that it would be impossible for A operators to dial four digits and still carry their existing loads. A new scheme, which has been developed and tried out successfully on working junctions between the Clerkenwell and National exchanges, eliminates the B operators and their positions and enables the A operators at manual exchanges to key-send the required numbers over the junctions direct into the digit-storing relay sets at the automatic exchanges. To carry out the scheme involves the installation of 4-frequency a.c. generators—quite small machines—and associated apparatus at 64 manual exchanges, modifications to approximately 37 000 cord circuits, fitting key-sending strips on about 2 300 A positions, and additional wiring throughout the manual exchanges for voice-frequency currents. The whole of the work at these exchanges is being carried out by Post Office staff, who are also fitting the voice-frequency relay sets in the automatic exchanges. The provision of new outlet groups and the modification of existing senders and junction-relay groups will be carried out by the contractors who installed the exchange equipments in the first instance. No B positions will be required in new automatic exchanges.

Four frequencies are required to signal any one of 10 digits and a cancel or start. The four frequencies are received on a set of four relays—"W," "X," "Y," and "Z" relays—and are successively stored in four sets of storage relays in the sender, corresponding to thousands, hundreds, tens, and units. When the first key—representing the first digit of the wanted subscriber's number—has been depressed by the A operator, any one or a combination of the four relays will be operated and the result immediately transferred to the thousands group in the sender, the second key depression transmits similarly to the hundreds, the third to the tens, and the fourth to the units group. At the conclusion the "sender" finally selects the wanted line. The combination scheme could be arranged as follows, although some modification exists in practice. W would be operated by one frequency, X by another, Y by the third, and Z by the fourth, corresponding to digits 1 to 4. Digit $5 = W + X$; $6 = W + Y$; $7 = W + Z$; $8 = X + Y$; $9 = X + Z$; and $0 = Y + Z$. Three frequencies are used on the cancel key, which is in practice depressed first to clear the outlets and to start straight. The frequencies are accepted either by mechanically-tuned relays or by simple resonant circuits operating into valve receivers, in the outputs of which ordinary telephone relays are fitted. When the A operator plugs into an outgoing junction jack, the apparatus at the incoming automatic exchange searches for and finds a free outlet, a free relay set, storage group and sender, and connects them to the junction. The common apparatus is then set free for the next call. The work on the scheme is well in hand and it is anticipated that it will be in full operation in the London area by about the middle of 1932.

Arrangements are also in hand for the application of key-sending on a 7-digit voice-frequency basis from manual to automatic exchanges. Under this scheme, indirect local traffic from manual exchanges in the London area will be routed via the 7-digit key-sending equipment installed at the most suitably situated adjacent automatic exchange. It should be possible also to key-send on this basis from manual exchanges outside into suitably selected automatic exchanges inside the area. In outlying manual exchanges on the fringe of provincial automatic areas, operators with light loads now dial direct into the automatic exchanges. Incidentally, the 4-frequency a.c. signalling scheme possesses also possibilities for operating from private branch exchanges, dialling from which is admittedly one disadvantage of automatic working. A scheme is being tried in which the four frequencies are sent out from the main exchanges on the parallel wires of the private branch exchange pairs and earth, and are then filtered-out at the private branch exchange, the four frequencies being then wired to a strip of 10 digit keys. By depressing these keys the operator sends back on the loop the individual frequencies as already described. The sending of 7 digits in this manner occupies no more time than that taken in a single revolution of a dial. The alternative to this scheme is some form of mechanical or power-driven key-sender at the private branch exchange, several of which have been tried experimentally.

Two automatic systems, incorporating new principles which will enable considerable economies in switching plant to be secured, are being investigated, one developed by Standard Telephones and Cables, Ltd., called the "Bypath" system, and the other by the Automatic Telephone Manufacturing Co., called the "Common Control" system. Each of the two systems substitutes an amount of common apparatus used during the conversation period which is less than that displaced from individual circuits. The two systems are both being tried out in director and in non-director areas, the former scheme at Bethnal Green and at Burton, and the latter at Arnold (London) and at Wigan.

A considerable advance has been made towards the standardization of equipment. Drawings and specifications have been prepared for single-sided racks and a Post Office standard telephone relay, designed for universal purposes, gives promise of high magnetic efficiency, freedom from faults and ease of adjustment and replacement. Sets of these relays have been working under practical conditions, and the claims made for them have been more than justified. The holding-time of directors (the common apparatus which stores up the letters and digits dialled by the calling subscriber, picks out the route and exchange, and finally sends out the stored impulses which select the wanted subscriber) has been reduced from 20 to 16 seconds.

PROGRESS IN THE PROVINCES.

Conversion to automatic working in the provinces is being undertaken wherever the economic and efficient life of existing exchanges is coming to an end, or where traffic requirements are promised distinct improvements from the new system. The number of automatic exchanges has increased from 125 at the date of the last review to 576 at the end of March 1931, and is now well over 600. The latter number requires further comment, however, since 359 of the total are rural automatic exchanges. Although these rural exchanges are quite small, their introduction (in February 1929) marks an important advance in telephone technique and one which may have a considerable effect upon the economic and social life of the community. Before the advent of the rural automatic exchange the Post Office experienced much difficulty in providing a satisfactory night service in country districts. A semi-party line scheme was in operation, but it was not much of a success; code-ringing at night time tries both the nerves and the patience of subscribers; sub-postmasters and sub-postmistresses did not like intermittent night work; and the absence of secrecy was often a fatal objection. The introduction of the rural automatic exchange has changed all this. It provides a highly efficient 24-hour secret local telephone service to the small community or scattered countryside, and also affords a link with the outside world at all hours by its junction circuit to the nearest parent exchange. The exchange consists of a small test frame for terminating the lines, a self-contained automatic unit, fitted in a damp- and dust-proof steel case, two 50-volt batteries of secondary cells, and a charging plant of about 1 h.p. which may be either oil-, gas-, petrol-, or electric-power-driven, depending upon the local conditions. All these parts are assembled in a small brick or stone building 14 ft. × 7 ft. 7 in. × 9 ft. high internally, erected to specification by local labour on a patch of land, some 60 ft. × 20 ft., purchased or rented from the landowner. The plant is normally unattended; the lineman calls to start the charging plant once every 3 or 4 weeks; and an automatic cut-off stops the charging machine when the battery voltage has risen to a predetermined limit. Provision is made at the parent exchange for ascertaining how the apparatus at the rural automatic exchange is functioning. The automatic unit has a capacity for 25 lines; when this number has been reached, a second unit is added; the capacity of the building is 4 units, i.e. 100 lines. So successful has been the scheme, that a new rural automatic exchange is being opened somewhere in the kingdom every day in the week. A public telephone kiosk is usually fitted at the roadside adjacent to the exchange. An allowance is given to the local engineer to enable him to maintain the plot and surrounding fence or hedge in a condition such as will harmonize with the amenities of the neighbourhood. Designs for a larger-size rural automatic exchange, capable of dealing with 200 lines, several of which may be private branch exchanges, have been approved and several of these larger installations are in operation. The broadcast service of the B.B.C., the Post Office rural automatic exchange, and daily postal delivery may do much to mitigate the rigour of the countryside in the wintertime, and thus tend to stop the drift to the towns. These services, together with the production of the cheap motor-car, the cinema, and the extension of the "grid" system, are factors to be recognized by the historian of the twentieth century.

Automatic service has been extended also to many of the larger towns and industrial areas. There are completed installations at Newcastle-on-Tyne, Preston, Gloucester, Ayr, Watford, Southend-on-Sea, Bristol, Middlesbrough, Blackpool, Bath, Macclesfield, Walsall, and Exeter, while the Birmingham and Manchester areas are now in process of conversion. There are at present some 5 000 public exchanges in the United Kingdom, with 2 015 000 telephone stations, of which 39 000 are public call offices, including kiosks. This shows an increase of 20 per cent since the date of the last review 3 years ago.

HAND MICRO-TELEPHONES.

One of the most interesting developments, from the point of view of the telephone user as well as from the transmission standpoint, has been the return of the hand micro-telephone. Before the arrival of the common-battery system the hand-set had achieved a certain amount of popularity, mainly by its convenience and ease of operation. The common-battery system with its automatic calling and clearing devices is successful as long as the originating subscriber, while speaking, maintains a closed loop on his line. The transmitter, being connected directly in the line circuit, must not break the continuity of the loop for any appreciable interval, because if it does a clearing signal is sent to the exchange. With the old micro-telephone the user was apt to let the transmitter turn over into a horizontal position, in which the carbon granules fell down on to the back plate and thus introduced a disconnection between the front and back electrodes. There were also disadvantages due to the fact that the old type of hand-set did not make allowance for the short-faced individual, i.e. a subscriber the distance between whose mouth and ear was less than the average, and in consequence his transmission suffered a loss of many decibels. The old hand-set handle was too long for the majority of users; speaking an inch away from a mouthpiece causes a loss of about 10 decibels. When the common-battery system was introduced, the disconnection trouble debarred the use of the hand-set, although several efforts were made to minimize the effect, e.g. the introduction of a permanent resistance across the transmitter, a short-circuiting press switch in the handle, etc. None of them was successful, however, and hand-sets were refused to users both in America and in this country for that reason and on account of their general inefficiency. Germany still retained this form of instrument, having in use a high-resistance type of transmitter which did not cause disconnections. The hand-set has now returned in an improved and more efficient form. Research, both here and in America, has succeeded in producing hand-set transmitters which do not disconnect in any position of the handle. The principal feature of the new transmitters is a very light flexible diaphragm, clamped round its periphery. In one type an insulated plunger is attached to the centre of a double-coned diaphragm and carries a polished carbon electrode mounted on a mica ring occupying the back of the granule chamber, the front electrode being a gold-plated brass ring. In another type, the diaphragm is fixed to a small aluminium drum faced on its inner side by a polished carbon disc which forms the front electrode, the back electrode also being of carbon. The two electrodes face each other centrally in the granule chamber, and are almost completely embedded in granules in any position of the transmitter. The transmitters are made up in capsule form to slip inside the case, the contacts being picked up by pointed contact springs, and a faulty inset can be replaced in a few seconds. There is nothing special about the receiver, which is of the ordinary watch type, but care had to be taken to prevent electrical and mechanical interaction between the transmitter and receiver, which might cause the latter to "howl." This, and also the prevention of excessive side-tone, has been successfully accomplished. The length of the handle was determined after measurement of some 150 heads at the Dollis Hill Research Station, and the distance from the centre of the receiver to the lip of the transmitter mouthpiece was fixed at 5·25 inches. The mouthpiece is shaped to accommodate users whose heads are beyond normal. An adjustable handle was ruled out for several reasons; first, on account of the trouble that might arise from unreliable and microphonic contacts, secondly, the danger of acoustic coupling between the transmitter and receiver, and, thirdly, the desirability of having a fixed size of cradle on the telephone to ensure reliability of contact when the hand-set is in position on the cradle. The army hand-set in the D.III telephone had a good type of adjustable handle, but it was not placed on a supporting cradle when not in use.

LINE PLANT.

The main backbone underground trunk network has been pushed northward as far as Huntly, Aberdeenshire, and repeater stations have been opened at Dundee and Aberdeen to serve the North. Many cross-country cables linking up the midland industrial cities have been installed to increase the facilities already existing between these centres. Repeater stations have also been opened at Liverpool (for that area and North Wales), Blackpool, Port Erin, and Belfast (in conjunction with the Blackpool–Isle-of-Man and Northern Ireland cables), and Torquay and Guernsey (for the new Channel Islands telephone service). The last-mentioned is of more than ordinary interest, as telephonic communication with Guernsey and Jersey is being provided by means of an existing single-core gutta-percha telegraph cable laid in 1914. The circuit from London is made up as follows: 4-wire underground London to Torquay, 215 miles; 4-wire aerial Torquay to Compass Cove, 13 miles; single-core submarine Compass Cove to Saints Bay, Guernsey, 80 nautical miles; 4-wire aerial Saints Bay to Guernsey exchange, 4 miles. Repeaters are fitted at London, Taplow, Marlborough, Bristol, Taunton, and Guernsey, with a 4-wire push-pull repeater at Torquay and a volume stabilizer at Taunton. The overall efficiency of the circuit is of the order of 8 decibels.

The comparatively heavy-gauge-conductor cable (several of the pairs being of 300-lb. copper) laid in 1916 between London and Liverpool and containing 52 pairs, has been pulled out and replaced by a star-quad cable, 25-lb. conductors, carrying 352 pairs. This cable passes through and serves Birmingham also, with repeaters at Fenny Stratford; between Birmingham and Liverpool a repeater station is being erected at Whitchurch to provide for development of the route. Star-quad cables were introduced because of their better space factor than cables of multiple-twin formation, the star-quad carrying as many physical pairs in the same diameter sheath as the other type could carry with phantoms on the side circuits. There is also less cross-talk between the pairs of a quad than between the side and phantom circuits of a multiple-twin cable, Improvement in manufacture has now produced such uniformity in circuit characteristics that the phantoms can be used in many cases on the pairs of star quads for telegraph purposes. An aerial lead-covered cable, 10-lb. conductors laid up in star-quad formation, with 37 quads in all, has been erected between Coulsdon and Brighton to serve as a London–Brighton toll cable. The sheath contains about 0·8 per cent antimony to resist vibrational stresses, and is 0·82 inch in diameter. The circuits are loaded with 120-mH coils at 2 000 yards spacing, the loading-coil pots being fitted on the poles. Repeaters of the "all-mains" variety are installed at Crawley. These are made from parts similar to those used in broadcast radio receivers and are consequently much cheaper than the repeaters fitted in more elaborate and permanent stations. This form of repeater will probably be widely used throughout the system when the "trunks on demand" service is in full operation. The London–Brighton circuits in the new cable are set at about 5 decibels. Mention was made in the last review of the trend towards lighter loading and the extension of simultaneous broadcasting through lightly-loaded conductors. Since then, provision has been made for music circuits in several through and interconnecting routes, especially those serving the neighbourhoods of the regional broadcasting centres. Table 4 gives particulars of those cables which contain music pairs. It will be observed that the screening of music circuits has been abandoned in the latest cable, Glasgow–Ayr. The screen was introduced to shield the music pairs from cross-talk and noise interference that might exist to some extent in the other pairs, and considerable immunity from that source was secured by the screen. It has been found, however, that satisfactory circuits can be secured without a screen in the latest cables, and selected pairs, usually in the outer layer, will be reserved for music distribution.

TABLE 4.

Paper-Core Screened-Conductor Cables Containing Pairs Allocated for Music Circuits.

Cable	Conductor weight (music pairs)	Loading		Method of make-up in cable
			Spacing	
	lb.	mH	miles	
Manchester–Huddersfield (1929), loaded in 1931 ..	40	16·0	1·136	4 screened quads
Manchester–Liverpool No. 5 (1930), loading in progress October 1931	40	15·5	1·136	4 screened quads
Dundee–Aberdeen (1930)	40	16·0	1–136	4 screened pairs
London–Liverpool (1930) —	40	15·5	1·136	4 screened pairs
Huddersfield–Leeds (1931)	40	16·0	1·136	4 screened quads
Glasgow–Ayr (1931)	40	22·0	0·568	Non-screened. Two groups of two quads each

The following cables have not yet been tested and accepted: Ayr–Stranraer; Stranraer–Port Kail; Belfast–Donaghadee. The Port Kail–Stranraer and Belfast–Donaghadee routes are being lightly loaded for carrier circuits and will provide additional circuits for Ireland. Incidentally, the former will be used in conjunction with the proposed transatlantic telephone cable. A special cable containing 19 screened 40-lb. pairs has been laid between the G.P.O. South Station and Broadcasting House for simultaneous broadcast programmes. The cross-talk in this cable is so small that special apparatus had to be devised to measure it. The apparatus is capable of indicating visually and with accuracy values of the order of 0·2 of a millionth of the disturbing voltage, when the latter is only 5 volts.

Corrosion of underground lead-covered cables by stray currents and by chemical action due to corrosive elements in local soils and water is becoming a serious matter. Some 1 150 cases of corrosion of Post Office cables were reported in the year 1930–31, the extent of the trouble may be even better appreciated by the fact that the replacement of the faulty lengths due to this cause cost the administration £27 700. Special protective treatments of the lead sheath, experimental trials of which are in progress in certain virulent areas, and close co-operation with and assistance from electric tramway engineers appear to be the most hopeful means of attacking the problem.

Motor transport is being more generally used in construction and maintenance work. Over 800 cars and vans and 1 760 motor-cycle combinations are in use by the Department.

THE POSITION ABROAD.

Direct telephone circuits have been opened between London, Marseilles, Oslo, Prague, and Budapest. From London there are now 31 circuits to Paris, 23 to Germany (10 Berlin, 7 Hamburg, 2 Dusseldorf, 2 Frankfurt, and 2 Cologne), 6 to Rotterdam, 2 to Stockholm, and 2 to Madrid. Latvia, Lithuania, and Finland are now within the reach of British subscribers, with charges recently reduced, and the south of Italy is now linked up. Italy is considering the laying of a new cable to Sardinia, while projects are in hand further east for cables from Sofia to Stamboul and into Asia Minor to Angora; also from Sofia southwards to Salonica and Athens. Telephonic communications between Egypt, Palestine, and Syria are under consideration. In Cairo a new automatic exchange of the rotary type has just been opened to serve some 14 000 subscribers, and there are 2 000 additional lines used for administrative purposes by the various ministries. Port Said, Suez, and Heliopolis are scheduled for conversion. A modern underground cable connects Cairo with Alexandria. The conversion of Lisbon to automatic working has commenced, and it is understood that orders have been placed by the Polish administration for their whole system to be modernized and changed over to automatic working. Five exchanges in Moscow and one in Rostov are said to be scheduled for automatic operation.

Constant progress in the direction of improvement in transmission and standardization of operation, and in international line-plant characteristics, is being fostered continuously by the action of the Comité Consultatif International des Communications Téléphoniques à Grande Distance, which meets in plenary session periodically to consider and approve the " answers to questions " sent out by the " rapporteurs " of the various commissions comprising the committee. The European representatives receive valuable assistance from the American Telephone and Telegraph Co., who place their experience and the results obtained in their research laboratories freely at the disposal of the C.C.I. The master transmission reference standard presented to the C.C.I. by the American Telephone and Telegraph Co. has been functioning in Paris under the control of international transmission experimentalists, one of whom is British. The artificial distortionless line is now exclusively used for standardization, since it has been discovered that an artificially-introduced distortion affects the results from different instruments in varying ways. A duplicate set has been built and set up at the British Post Office Research Station, Dollis Hill.

Carrier circuits have been successfully superposed on the balata-covered cable connecting the north and south islands of New Zealand.

The Position in America.

The report of the directors of the American Telephone and Telegraph Co. addressed to the stockholders for the year ended March 1931, begins: " The depression which affected business in general during 1930 inevitably affected the telephone business, but not in a way or to an extent to disturb the fundamental objectives of the Bell system. It has been able to improve and extend telephone service." The extent to which business was affected may be judged by the fact that 122 500 additional telephones were installed during the year, as against 821 400 in 1929. The average time to complete trunk calls throughout the system was lowered by 12 seconds to an average of 1 minute. Local telephone conversations increased by 2 per cent and long-distance conversations by 1 per cent during the year. The number of hand-sets was doubled, to reach 2 000 000. The number of automatic telephone stations is now over one-fourth of the total number of stations in operation on the Bell and connecting companies' services, which reached the enormous total of 20 098 059 on the 31st December, 1930.

More and more attention is being paid in the United States to improvements in articulate transmission. The Bell Telephone Laboratories have been and are conducting a long series of experiments on selected lines of various transmission values to determine the number of repetitions on such lines, with a view to establishing a new standard of service. It is recognized that two circuits of practically the same electrical characteristics and with similar apparatus at the ends may not give equal service; more repetitions may be required on one than on the other. Noise on the line must be taken into account; the acoustic properties of users' premises and noise from external sources have serious results on accurate reception. It has been said that repetition increases by 100 per cent in the summer-time in New York, when the office windows are open. The results from these experiments, which naturally have to be prolonged, will be correlated to other figures obtained from artificial lines on which various types of apparatus are fitted and which can be subjected to artificially-produced noises. By this means it is hoped to build up a systematized grading of service which will cover not only volume or amplitude (in decibels), but also freedom from noise and other effects that interfere with the accuracy and naturalness of reception. Advantage is being taken of the improvements to be obtained by the use of mechanical acoustic filters both in transmitters and in receivers. Attention has already been directed to the great increase in the long-distance mileage in the United States. In addition, the laying of a fourth submarine cable between Key West and Havana was completed in January 1931. The cable is non-loaded and is insulated with paragutta. This material, which has also been tested in England, gives a better ratio of leakance/capacitance than any other plastic dielectric. The new cable is equipped with carrier apparatus which provides three telephone channels and one d.c. telegraph circuit; these channels can be added to as required. The telephone facilities afforded by the new cable are equal to those furnished by the three older cables together.

The following miscellaneous statistics relating to dial (automatic) telephone operation in the United States have been kindly supplied by Col. H. E. Shreeve, technical representative of the American Telephone and Telegraph Co. in Europe.

1. Number of dial (automatic) stations in U.S.A., January, 1931:—

Bell	4 977 000
Other	588 000
Total	5 565 000

Percentage dial (automatic) to total stations, 1st January, 1931:—

Bell	31·7
Other	13·0
Total	27·5

2. Dial (automatic) exchanges, lines and stations, 30th June, 1931:—

(*a*) *Panel.*

Number of exchanges in New York City	68
Number of exchanges in U.S.A. (including New York City)	235
Number of lines in U.S.A.	1 332 294
Number of stations in U.S.A.	2 555 893

Additional panel exchanges scheduled for cut-over during year ending 30th June, 1931:—

New York City	10
Remainder of U.S.A.	39
Total	49

(*b*) *Step-by-Step* (*Bell System*), 30th June, 1931.

Number of exchanges in U.S.A. ..	426
Number of lines in U.S.A.	1 476 916
Number of stations in U.S.A.	2 720 277

Additional step-by-step offices are scheduled to be cut into service during year ending 30th June, 1932, in 32 cities and towns which did not have such equipment in service on 30th June, 1931. A total of 65 exchanges are scheduled for service during the year ending 30th June, 1932, in 32 cities and towns and in other cities which had step-by-step equipment in service on 30th June, 1931.

3. Independent companies in U.S.A. (including all Bell connecting and non-connecting telephone companies).

Number of exchanges:—

	31st Dec., 1929	30th June, 1931
Manual	12 879	*
Dial (automatic)	248	*
Total	13 127	12 882

Number of stations—

Manual	4 009 020	*
Dial (automatic)	644 508	*
Total	4 653 528	4 504 000

SUBMARINE TELEPHONE CABLES.

The submarine cables connecting England with the Isle of Man and Northern Ireland, which were under construction at the date of last review, have now been laid and are operating very successfully. By means of the Isle-of-Man–Blackpool length a broadcast commentary on the Tourist Trophy motor-cycle races held in the Island was given last year by the B.B.C. A carrier system has been superposed on a pair in that length and its possibilities demonstrated, and successful experiments in the same direction have been carried out on a pair in one of the balata-covered cables from Port Erin (Isle of Man) to Ballyhornan (Northern Ireland). A carrier channel is also working on the Anglo-Dutch No. 3 cable, in addition to seven double-superposed circuits already installed on that route, which afford 16 channels on one cable containing 16 wires, and 16 channels on the third cable which contains 17 wires, one wire being in the centre of four quads. The same principle of double superposition has been applied to the Anglo-French and Anglo-Belgian (1926) cables, and 3 additional circuits in each cable have been found to be practicable. Thus a total of 13 additional Continental circuits have been provided by this means alone, with no extra costs so far as the submarine links are concerned.

* No information.

TABLE 5.—*List of Lead-Covered Submarine Telephone Cables Landing in England, 1st January, 1932.*

Cable	Terminal points	Approximate length	Date laid	Attenuation constant per nautical mile of side-circuit loop*	Characteristic impedance*	Type of loading
		nautical miles		nepers	vector ohms	
Anglo-Dutch No. 2 (4 quads) ..	Aldeburgh–Domburg	83	August 1924	0·0200	$414\angle 6^\circ\,22'$	Continuous
Anglo-Dutch No. 3 (4 quads + 1) ..	Domburg–Aldeburgh	86	April 1926	0·0180 outers	$439\angle 6^\circ\,0'$	Continuous
				0·0227 centre	$286\angle 8^\circ\,17'$	
Anglo-Belgian (1926) (7 quads) ..	Canterbury–La Panne	65	July 1926	0·0276 outers	$388\angle 9^\circ\,0'$	Continuous
				0·0274 centre	$388\angle 8^\circ\,15'$	
Anglo-French (1926) (7 quads) ..	Canterbury–Boulogne	49	March 1927	0·0273 (mean)	$386\angle 8^\circ\,42'$	Continuous
Isle of Wight (7 quads)	Lumps Fort–Nettlestone Point	5·35	September 1928	0·0326 outers	$815\angle 6^\circ\,19'$	Coil-loaded
	Portsmouth–Seaview	—	—	0·0326 centre	$805\angle 6^\circ\,43'$	
Isle of Man (4 quads + 1)	Blackpool–Port Erin	69	June 1929	0·029	$369\angle 9^\circ\,33'$	Continuous
Anglo-French (1930) (7 quads) ..	Seabrook–Boulogne	34	August 1930	0·0264 (mean)	$477\angle 7^\circ\,42'$	Continuous
Anglo-Belgian (1930) (7 quads) ..	Canterbury–La Panne	66·5	September 1930	0·0282 (mean)	$380\angle 10^\circ\,0'$	Continuous
Isle of Wight (1930) (7 quads) ..	Stone Point–Gurnard Bay	2·12	December 1930	0·0209 (mean)	$1\,330\angle 2^\circ\,40'$	Coil-loaded

* Attenuation constant and characteristic impedance with 1 mA testing current at a frequency of 5 000 radians per second.

Extra carrier circuits can be provided as required on the Anglo-Dutch, Anglo-Belgian, and Anglo-French routes. As will be seen from Table 5, an additional Anglo-French cable, an Anglo-Belgian cable, and a cable to the Isle of Wight were laid in 1930. The Anglo-French cable was manufactured in Germany under reparations agreement and laid by the German cable ship "Norderney." The mechanical structure and electrical characteristics of the two channel cables are practically identical with those of the 1926 cables. There is one departure from 1926 practice in the case of the 1930 French cable, in that the continuous loading ends at Seabrook where the sea-cable pairs are joined to 4-wire terminations of a coil-loaded underground cable from Canterbury. In the 1926 cable the continuous loading was carried underground to the repeater station at Canterbury. Two new projects are under consideration at the moment: (*a*) a new unloaded cable from Dover or St. Margarets Bay to France, with repeaters at the cable ends; and (*b*) a cable made up in short lengths with one-half of the conductors continuously loaded and laid up on one side of a diametrical screen, the other half of the pairs to be unloaded. When the short lengths have been made up, the loaded pairs in one length are to be jointed through to unloaded pairs in the next length, and vice versa. Considerable economy in the cost of loading would thus be secured and, since the loaded and unloaded lengths would be quite short and the loading light, the cable as a whole would behave as if it were very lightly loaded and reflection losses and distortion would be slight. The effects of reflection at a fault in a submarine cable have been utilized in an ingenious a.c. method of fault localization which can be used in cases where it would not be possible to use a.c. bridge methods of the Varley type. The method demands full knowledge of the characteristics of the cable at the time of test, and periodical measurements of various cables have been made throughout the year so that the extent of the changes due to temperature variations at the sea bottom can be allowed for at any time. An account of the development of the test has recently been published.*

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* *Journal of the Institution of Post Office Electrical Engineers*, 1930, vol. 23, p. 42.

FARADAY CENTENARY CELEBRATIONS, 1931.

I.E.E. FARADAY CENTENARY CELEBRATIONS MAIN COMMITTEE.

Mr. C. C. Paterson, O.B.E., President, 1930–31 (*Chairman*).

Mr. P. F. Rowell (*Secretary*).

Lieut.-Col. W. A. Vignoles, D.S.O. (*Hon. Secretary*).

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Mr. N. Ashbridge, B.Sc.
Mr. Ll. B. Atkinson.
Mr. F. W. Crawter.
Col. R. E. B. Crompton, C.B.
Mr. D. N. Dunlop, O.B.E.
Captain P. P. Eckersley.
Lieut.-Col. K. Edgcumbe, T.D., R.E.T.(Ret.).
Mr. H. Willoughby Ellis.
Mr. R. Milward Ellis.
Mr. A. J. Fuller.
Mr. J. M. Kennedy.
Mr. E. Leete.
Mr. W. M. Mordey.
Mr. C. G. Morley New.
Mr. R. W. L. Phillips.
Mr. F. W. Purse.
Col. Sir Thomas F. Purves, O.B.E.
Mr. C. Rodgers, O.B.E., B.Sc., B.Eng.
Mr. J. Rowan.
Lord Rutherford, O.M., F.R.S.
Mr. V. Watlington, M.B.E.
Mr. A. P. Young, O.B.E.

REPORT OF MAIN COMMITTEE.

Whilst the Albert Hall Exhibition constituted the greatest single concentration of effort of the electrical industry, to celebrate the researches of Faraday, the additional activity all over the world in the form of meetings, lectures, exhibitions, civic functions, special illuminations and the like, attracted widespread attention and interest.

In the space available it is impossible to enumerate all these activities in detail. The most important of the events in London were the meetings organized by the Royal Institution at the Queen's Hall and by the Institution of Electrical Engineers at Kingsway Hall, followed at the close of the week by a banquet given by the Government to all the delegates who attended the celebrations. Particulars will be found in the Faraday Number of the *I.E.E. Journal* (November 1931). The full report of the Exhibition and Publicity Sub-Committee is given below.

At Liverpool an exhibition, attended by 17 000 persons, was held and was preceded by a civic reception and luncheon. At Newcastle, a lecture by Prof. W. M. Thornton was attended by over 2 000 persons and was supported by the civic authorities and by other mayors from Tyneside. A similar civic meeting at Hull (North Midland Centre) was addressed by Principal Morgan and was equally well attended. At Birmingham a lecture was delivered by Mr. F. Forrest, the attendance being over 800. Prof. J. T. MacGregor-Morris lectured at Loughborough (East Midland Sub-Centre) and Prof. H. Stansfield and Prof. G. D. A. Parr at Southampton and Portsmouth (Hampshire Sub-Centre) respectively. Manchester (North-Western Centre) organized a large conversazione in which other interested societies co-operated. The Western Centre participated in a similar conversazione at Cardiff, and in a commemorative meeting at Exeter, which included an exhibition, and lectures were delivered at other towns in the area.

On many of these occasions the broadcast of Sir William Bragg's address at the Queen's Hall, and also the Faraday film, formed a feature.

Overseas, important meetings were held in Sydney, Wellington, and Brisbane, at which prominent men gave addresses (see *I.E.E. Journal*, December 1931, page 97).

In Paris the Société Française des Électriciens held a special Faraday Session, at which its President, Prof. Henri Chaumat, delivered an address. The Society followed this with a banquet to which representatives of the I.E.E. were invited as guests.

The Institute of Electrical Engineers of Japan issued in September a Faraday Memorial Number of their *Journal*. In addition, on the 16th September the President of the Japanese Institute, Dr. K. Takatsu, broadcast throughout Japan a popular lecture on Faraday's work and achievements. The Centenary was also celebrated in Tokyo under the auspices of various technical organizations.

The British Electrical Development Association supported all the foregoing activities in Great Britain, and used its organization in many other ways for calling public attention to the celebrations. Amongst these activities was the promotion of the floodlighting of many public buildings in the towns and cities of the country, and the distribution, with the assistance of educational authorities, of about 100 000 brochures on the life of Faraday. Over 2 000 handbooks containing lecture notes were also issued to local scientific societies, etc., and school-essay competitions were arranged by the Association.

CLIFFORD C. PATERSON,
Chairman of Main Committee

December, 1931.

EXHIBITION AND PUBLICITY SUB-COMMITTEE.

Lieut.-Col. W. A. Vignoles, D.S.O. (*Chairman*).

Mr. J. I. Bernard (*Secretary*).

Mr. W. Imrie-Smith (*Asst. Secretary*).

Commander Rollo Appleyard, O.B.E.
Prof. H. E. Armstrong, F.R.S.
Sir William Bragg, K.B.E., F.R.S.
Mr. A. C. Cramb.
Captain P. P. Eckersley.
Mr. H. Willoughby Ellis.
Mr. R. Milward Ellis.
Mr. P. Good.
Mr. W. J. Jones.
Mr. F. R. Lewis.
Mr. A. Marshall.
Mr. T. Martin.
Mr. W. M. Mordey.
Mr. C. C. Paterson, O.B.E.
Mr. R. W. L. Phillips.
Dr. W. G. Plummer, M.Sc.
Col. Sir Thomas F. Purves, O.B.E.
Sir Robert Robertson, K.B.E., F.R.S.
Mr. C. Rodgers, O.B.E., B.Sc., B.Eng.
Mr. P. F. Rowell.
Mr. C. Holmes Waghorn.
Mr. A. P. Young, O.B.E.

REPORT OF THE EXHIBITION AND PUBLICITY SUB-COMMITTEE.

On the 5th February, 1929, the Managers of the Royal Institution called a meeting of representatives of all societies and associations considered likely to be interested in the organization of celebrations to commemorate the centenary of Faraday's discovery of electromagnetic induction. This meeting was held under the chairmanship of Sir Arthur Keith, F.R.S., at the Royal Institution, and it was eventually decided that two committees should be formed, one under the auspices of the Royal Institution and a second under the auspices of the Institution of Electrical Engineers.

These two committees were instructed to consult together and to co-operate in the organization of celebrations of a suitable character.

On the 17th April, 1929, the Institution of Electrical Engineers called a meeting of representatives of the associations connected with the electrical industry, and at this meeting an Institution of Electrical Engineers Faraday Centenary Celebrations Committee was appointed to confer with the Royal Institution and to prepare a report. The appointment of this committee was subsequently confirmed by the Council of the Institution of Electrical Engineers. This committee held a number of meetings and considered, among other things, a scheme for an Exhibition which, in December 1928, had been put forward by Colonel Vignoles, the then Director of the British Electrical Development Association, in a memorandum to the Executive Committee of that Association; this scheme suggested that the celebrations should include " a Faraday Centenary Electrical Exhibition designed to show the latest developments of all branches of science, engineering, and industry, that have been derived from or benefited by the work of Faraday."

It was eventually decided to include such an Exhibition as part of the celebrations, the Royal Institution undertaking to co-operate in dealing with the scientific aspects of the Exhibition.

The Committee agreed that the Exhibition should be designed to interest the public in the work of Faraday, to show something of that work, and to demonstrate the great developments that have followed his discoveries.

It was decided that the Exhibition should be, as far as possible, devoid of any element of advertisement, and be mainly educational in character, and while the exhibits would necessarily have to be somewhat technical, efforts should be made to interest the general public.

ORGANIZATION.

The Faraday Celebrations Committee of the Institution of Electrical Engineers appointed the Exhibition Sub-Committee, which consisted of representatives of the Institution of Electrical Engineers, the Royal Institution, the Federal Council for Chemistry, and other societies and associations, to act as an Executive Committee to organize and carry out the Exhibition. Arrangements were made with the British Electrical Development Association to provide the necessary secretarial facilities, Mr. J. I. Bernard, a member of the staff of that Association, being appointed Secretary to the Sub-Committee; Mr. W. Imrie-Smith was later appointed Assistant Secretary and took over the whole of the duties on Mr. Bernard being incapacitated through illness.

Two panels, to deal with questions of publicity and finance respectively, were subsequently set up by the Sub-Committee. Mr. F. R. Lewis, of Exhibition Organizers, Ltd., was consulted as to the organization and was eventually appointed Manager of the Exhibition. His experience and expert assistance largely contributed to its success.

FINANCE.

Ordinary commercial exhibitions are financed to a very large extent by the firms exhibiting, who not only provide at their own expense the exhibits and the stands which they erect, but also, by paying a rental for the space occupied, provide a large part of the cost. The amount received from gate money is in many cases sufficient to pay only a small portion of the total expenses. In the case of the Exhibition contemplated it was realized that it was impossible to ask firms or commercial associations to pay for space, and that, therefore, if the Exhibition were to be carried through, some monetary contributions would have to be obtained from other sources. Eventually the Institution of Electrical Engineers agreed to meet any expenditure on the Exhibition up to a total of £10 000, while a further sum of £1 642 was collected by the Federal Council for Chemistry from firms and others connected with the chemical industry. With these two amounts guaranteed, and an allowance made for admission receipts, the maximum expenditure which the committee might incur was fixed at £12 350.

The cost of preparing the Hall, the stands, the supply of electricity and all incidental expenses were met from the funds thus provided.

The various associations connected with the electrical and chemical industries were approached and were invited to provide displays to illustrate certain aspects of the developments that had arisen from Faraday's work, the expense of such displays being borne by the association concerned.

The principal displays were provided, in the manner indicated, by the British Electrical and Allied Manufacturers' Association, the Cable Makers' Association, the Electric Lamp Manufacturers' Association, the British Electrical Development Association, the British Broadcasting Corporation, the General Post Office, the Central Electricity Board, and the Federal Council for Chemistry, while the Royal Institution made and provided apparatus and arranged the demonstrations on the eight stands surrounding the central feature.

In a building such as the Albert Hall, the authorities very rightly insisted upon all electrical and other work being carried out in a very substantial manner, so as to avoid all risk of fire or other damage, and this naturally increased the cost of the work. The statement of accounts submitted to the Council shows that the expenditure amounted to £12 023, or £327 below the limit fixed, while owing to the receipts being considerably greater than the amount estimated, the amount called upon from the funds of the Institution of Electrical Engineers is some £1 800 less than the £10 000 guaranteed.

Including the amounts expended by exhibitors on their displays, the total cost of the Exhibition is estimated at not less than £20 000. In the present position of industry this must be considered to be a very satisfactory effort on the part of the electrical and chemical industries.

All financial matters were treated on a credit basis, and the Committee never handled any actual funds. In accordance with the procedure agreed upon by the Finance Panel at a meeting held on the 21st July, 1931, all accounts were submitted to the scrutiny of Colonel Vignoles as Chairman of the Committee and, after his endorsement, were forwarded to the Institution of Electrical Engineers, who made the actual payments.

Finally, the various statements of accounts, prepared for the Committee by the Assistant Secretary, were checked by the accountant of the Institution of Electrical Engineers and will subsequently be audited by its auditors.

THE EXHIBITION.

A number of halls were considered in the first instance as a possible site for the Exhibition, but it was eventually decided, taking all things into consideration, and especially in view of the character of the Exhibition desired, that the Royal Albert Hall, while rather small for the scope of the exhibits to be displayed, was, owing to its shape, and the atmosphere which it was thought possible to create, the most suitable. Arrangements were therefore made for the use of this Hall.

The general scheme of the Exhibition eventually decided on was to place a statue of Michael Faraday in the centre on a raised platform; on this were cases containing items of personal interest, such as diaries and laboratory notes, while three rows of stands surrounded the central feature and were arranged with exhibits to show progressively from the centre to the circumference Faraday's work and the developments that had come from it.

The fundamental experiments carried out by Faraday were arranged by the Royal Institution on the eight stands immediately surrounding the centre, while the remainder of the space was devoted to the display of modern developments in the various electrical, electrochemical, and chemical industries.

In arranging the displays, assistance was received from a very large number of collaborators, apart from the associations mentioned above; reference is made to these in the Souvenir Catalogue, in which every effort was made to give a complete list of acknowledgments.

DECORATIVE LIGHTING SCHEME.

A special lighting and decorative scheme was designed for the Exhibition Committee by the Lighting Service Bureau of the Electric Lamp Manufacturers' Association, and was eventually adopted, the Association kindly presenting all the lamps required. The whole ceiling was covered with a large velarium in white and primrose; the main illumination was provided by large floodlights concealed in the balcony, which projected light on to the velarium; while a large ornamental lighting fitting some 40 feet in length was suspended in the centre of the Hall. Additional decoration was provided by 132 wall fittings on the pillars round the gallery, and eight luminous arches were arranged in the stands surrounding the central feature.

The whole lighting scheme was considered to be extremely successful, the illumination on the floor being of high intensity and of a very pleasing character.

The electric power used in the scheme amounted to 256 kW. Altogether the lighting was, as was intended by the Committee, an attractive feature of the Exhibition, and the design reflected great credit on Mr. R. W. Maitland, the Lighting Service Bureau architect, who prepared the scheme.

In addition to the exhibits in the main Hall and entrance, a reproduction of Faraday's Laboratory was arranged in the King's Room by the Wellcome Historical and Medical Museum, and short lectures on Faraday and his work were there given.

ADDITIONAL EXHIBITS.

In a basement adjoining the entrance hall a high-frequency furnace was shown in operation, where visitors could see small busts of Faraday being cast, these busts being subsequently placed on sale at the bookstall.

In the rehearsal room a talking film on Michael Faraday was shown at periodical intervals throughout each day of the Exhibition, with the exception of the 24th September, when a special lecture, fully illustrated by experiments, was given by Dr. Cramp, of Birmingham University.

The film on Michael Faraday was produced at the Engineering Research Laboratory of the British Thomson-Houston Co., Ltd., at their own expense, the Exhibition Committee merely buying such copies of the film as were required for use. The film shows Sir William Bragg speaking at Faraday's lecture table and describing Faraday's work, and some of Faraday's experiments are included, while Faraday himself is seen making his famous experiment which led to the discovery of electromagnetic induction.

DEMONSTRATORS AND GUIDES.

In order that the numerous experiments to be shown should be efficiently explained to visitors, a volunteer staff of 270 demonstrators was organized. The members of this staff were drawn chiefly from the Students' Section of the Institution of Electrical Engineers, the colleges of the University of London, technical colleges, and other educational and scientific institutions. They were arranged in appropriate groups by the Assistant Secretary and Mr. A. Marshall, and were instructed by Sir William Bragg and his staff at the Royal Institution, and by Sir Robert Robertson at the Government Laboratory, while Prof. Darling, Mr. W. F. J. Walton, and Mr. F. G. H. Tate assisted with the organization and allocation of the demonstrators for duty with the various exhibits. The demonstrators carried out their duties with efficiency and with great enthusiasm, and undoubtedly assisted the public very greatly to appreciate what they saw.

SOUVENIR CATALOGUE AND GUIDE.

As a key to the exhibits and as a memento of the occasion, a Souvenir Guide and Catalogue of 248 pages was compiled. This contained not only descriptions of the exhibits themselves, but also articles by Sir William Bragg, Prof. H. E. Armstrong, and Mr. A. Marshall as introductions to the various sections in which the exhibits were grouped. The whole of the exhibits were catalogued under stand and item reference letters and numbers, and a reference to this catalogue shows that over 700 items, large and small, were displayed. Over 7 400 catalogues were sold at the Exhibition at the full price of 1s. each.

OPENING OF THE EXHIBITION.

The whole Exhibition was complete and every exhibit in its place by the evening of Tuesday, 22nd September, when the Institution of Electrical Engineers held a conversazione at the Exhibition and some 2 300 members and their friends attended. A private view was held on the morning of Wednesday, 23rd September, and on the afternoon of the same day at 4.30 p.m. Mr. C. C. Paterson, President of the Institution of Electrical Engineers, presided at the ceremony when General the Right Hon. J. C. Smuts, P.C., opened the Exhibition. The proceedings at this opening ceremony were, through the co-operation of the General Post Office, the British Broadcasting Corporation, and Messrs. Standard Telephones and Cables, Ltd., amplified in the Hall, and broadcast by the British Broadcasting Corporation. A vote of thanks to General Smuts was proposed by Colonel Crompton, and the proceedings also included an address by Dr. Jewett, of the American Institute of Electrical Engineers, who, on behalf of American and other scientific societies abroad, extended greetings to British scientists gathered for the opening of the Faraday Exhibition. He spoke from Boston, U.S.A., his words being carried over one of the Post Office transatlantic commercial radio-telephone circuits to the Exhibition.

PUBLICITY.

The problem with which the Publicity Panel had to deal was to secure as much publicity as possible for the Faraday Celebrations generally, with a view to interesting the public in the Exhibition and to securing the attendance of as many visitors as possible, bearing in mind the size of the Royal Albert Hall and that very large numbers would be an embarrassment.

The work of the Panel was carried out in three ways:—

(*a*) By the use of circular letters and the distribution of programme folders, poster stamps, showcards, and window bills for display free of charge, the number distributed being as follows:—

34 000 programme folders;
18 000 window bills;
4 000 showcards;
500 000 poster stamps.

(*b*) By posters and by paid announcements in the Press, and other paid-for advertising.

(*c*) By interesting the Press and supplying them with material for the preparation of articles on Faraday and the Exhibition.

Propaganda and advertising were placed in the hands of Carlton Publicity, Ltd., while Mr. C. Holmes Waghorn was appointed to deal with editorial work and to act as general Press agent.

In accordance with a schedule prepared early in the year, circular letters enclosing or offering window bills, programme folders, showcards, etc., were sent to foreign legations, overseas clubs, railway and steamship companies, chambers of commerce, travel agencies, hotels, supply undertakings, and universities. The number of folders, bills, and showcards may appear to be very small, but it is doubtful whether a larger expenditure would have produced any proportionally greater results.

A very striking poster design by Mr. E. McKnight Kauffer was adopted and displayed on 2 000 sites of the London and suburban railways; the Underground Railways also placed 8 000 posters of window-bill size in their trains, and 350 omnibus-side sites belonging to the London General Omnibus Co. were utilized.

The Press advertising was restricted to one insertion of a display advertisement in 15 national and 10 provincial papers, while during the Exhibition an announcement of approximately four lines appeared daily in 20 national papers.

A notable feature of the Press advertising was the front page of the special Faraday Number of *The Times* on Monday, 21st September, announcing the Faraday Celebrations and the Exhibition. This page, the design for which was prepared by Mr. Clifford Webb, was paid for jointly by the Royal Institution, the Exhibition Committee, and the British Electrical Development Association.

The preparation of suitable material for issue to the editors of the Press all over the world was commenced at an early date, a special mailing list of nearly 900 names was prepared, and material in several languages was dispatched to British and foreign newspapers and journals in accordance with a carefully arranged schedule, commencing early in the year.

On the 19th September a Press room was established at the Royal Institution, and was moved to the Royal Albert Hall on the 21st September, where it remained throughout the Exhibition. Tables of statistics, interesting items about the Exhibition, records, and photographs were prepared and displayed for the use of the Press. The attendance books show that representatives of 92 news agencies, newspapers and technical publications, etc., called for information.

There is no doubt that the Faraday Celebrations and the Exhibition interested the Press very much, as is shown by the following table giving the amount of Press cuttings received up to the end of October:—

Class of publication	Column inches
National newspapers	5 257
Magazines	699
Technical and trade publications ..	4 430
Suburban newspapers	1 784
Provincial newspapers	14 064
Foreign newspapers	4 712
Total	30 946

The value of this publicity is difficult to assess, but the amount of space, if paid for at the usual advertising rates, would have cost nearly £43 000.

A considerable amount of money was spent in providing the Press with suitable photographs, and examination of the guard books in which cuttings are mounted shows that this policy was justified, as it undoubtedly assisted in securing editorial notice.

FARADAY FILM.

The film of Michael Faraday having been presented to the Exhibition Committee, it was thought very desirable to secure as wide a circulation as possible for this, although it was not strictly an exhibition matter. Eventually, through the efforts of Mr. F. A. Enders, of Film Booking Offices, Ltd., the Faraday film was accepted by the Gaumont British Company for exhibition in 64 of their theatres. This itinerary commenced on the 13th September and is still being carried out. In addition to the above, there are other bookings which have been arranged in the provinces by the area officers of the British Electrical Development Association.

RESULTS OF THE EXHIBITION.

It is difficult to assess the results of an Exhibition such as the one under consideration, but it can be claimed that the celebrations and the Exhibition did succeed in interesting the public in Michael Faraday as a man and scientist, and in the part played by the electrical, chemical and other industries in modern civilization. During the period the Exhibition was open it is estimated that some 50 000 people, including season-ticket holders, obtained admission. That the educational nature of the Exhibition was appreciated is clearly marked by the fact that 398 schools organized parties, aggregating 13 179 students, to visit the Exhibition, these coming from places as far away as Canterbury, Ipswich, Nottingham, Southampton, Winchester, Cheltenham, Southend-on-Sea, Tonbridge, and York. One party, consisting of 239 boys, came from Merton in six motor-coaches.

Despite the fact that only about 80 people could be seated at one time in the rehearsal room and that there was an admission charge of 2d., the Faraday film was visited by 6 124 people.

Looking at the figures, it may be claimed that the number attending the Exhibition was as large as was desirable. If the attendance had been greater the Hall would have been overcrowded on several days and the doors would probably have had to be closed; 50 000 is, in fact, about as many as can be handled at an exhibition in the Albert Hall during a period of 10 days. Throughout the Exhibition there were queues to view the Faraday film, the Faraday laboratory, and the operation of the high-frequency furnace.

The demonstrators report that nearly all the members of the public with whom they conversed found some special items of interest, and that a very large number of non-technical people sought information on matters of a technical or semi-technical character.

CONCLUSION.

Arrangements are being made to send to all the demonstrators, and firms and individuals who gave assistance to the Committee, specially bound copies of the Faraday Number of the *I.E.E. Journal* and of the Guide and Catalogue to the Exhibition, with notes of thanks for the assistance rendered.

In conclusion the Committee would like to acknowledge, and to express once again their very sincere thanks for, the assistance which has been given to them from every quarter. They would also like to record their appreciation of the extraordinary way in which hundreds of people volunteered assistance and helped to give the Faraday Centenary Exhibition its unique character, and to make it memorable in the history of British science and industry.

W. A. VIGNOLES,

Chairman, Exhibition and Publicity Sub-Committee.

November, 1931.

THE RESISTANCE-TERMINATED, BALANCED SEA-EARTH OF A TAPER-LOADED SUBMARINE TELEGRAPH CABLE.*

By C. R. Fielder, Graduate.

(*Paper first received* 19*th March, and in final form* 15*th May*, 1931.)

Summary.

In order to minimize the effect of extraneous disturbance in submarine telegraph cables operated duplex, it has been the practice for some time past to make the earth connection of the artificial line several miles from shore. For this purpose a length of twin-core cable was laid, the seaward end of the conductor of the second or sea-earth core being connected to the sheathing wires.

With the advent of the loaded cable, in order to take full advantage of the possible great gain in speed a more effective method of interference elimination became necessary. The method now generally adopted provides for a twin core extending from the shore to a point where the cable reaches deep water. The seaward end of the second core is joined to a length of core having a stranded manganin-wire conductor, the free end of which is connected to the sheathing wires in the usual manner. This second core is termed the "balanced sea-earth."

This paper deals with the problem of computing the value of the resistance of the manganin core for a taper-loaded cable.

Mention is made of the function of a taper-loaded cable as a high-speed duplex telegraph cable.

High or low frequencies referred to in the paper are within the band of telegraph signalling frequencies.

List of Symbols Used in the Paper.

E_s = sending-end voltage.
I_s = sending-end current.
E_1 = incident voltage.
I_1 = incident current.
E_2 = resultant voltage.
I_2 = resultant current.
E_3 = reflected voltage.
I_3 = reflected current.
Z_0 = characteristic impedance, in ohms

$$= \sqrt{\left[\frac{R + j\omega L}{G + j\omega C}\right]} = R_0 - jX$$

Z = sending-end or terminal impedance, in ohms.
Y = sending-end or terminal admittance = $1/Z$.
C = capacitance, in farads per nautical mile.
G = leakance, in mhos per nautical mile.
L = inductance, in henrys per nautical mile.
R = effective resistance, in ohms per nautical mile.
P = propagation constant

$$= \sqrt{[(R + j\omega L)(G + j\omega C)]} = \alpha + j\beta$$

α = attenuation constant, in hyperbolic radians per nautical mile.
β = wavelength constant, in radians per nautical mile.

(1) Introduction.

Continuously-loaded submarine telegraph cables designed for simplex working have been in use for the past six years. The difficulty of balancing cables of this type for duplex working has already been referred to in a paper on the subject.†

Variation of the added inductance along the cable near the sending-end causes irregularities, due to reflection phenomena, in the impedance/frequency curve. At any one frequency the impedance is a highly complex function of the current at the sending-end, and for constant current values the impedance is a highly complex function of the frequency. This is due to the electrical characteristics of the loading material causing both added resistance and added inductance to vary with current and frequency.

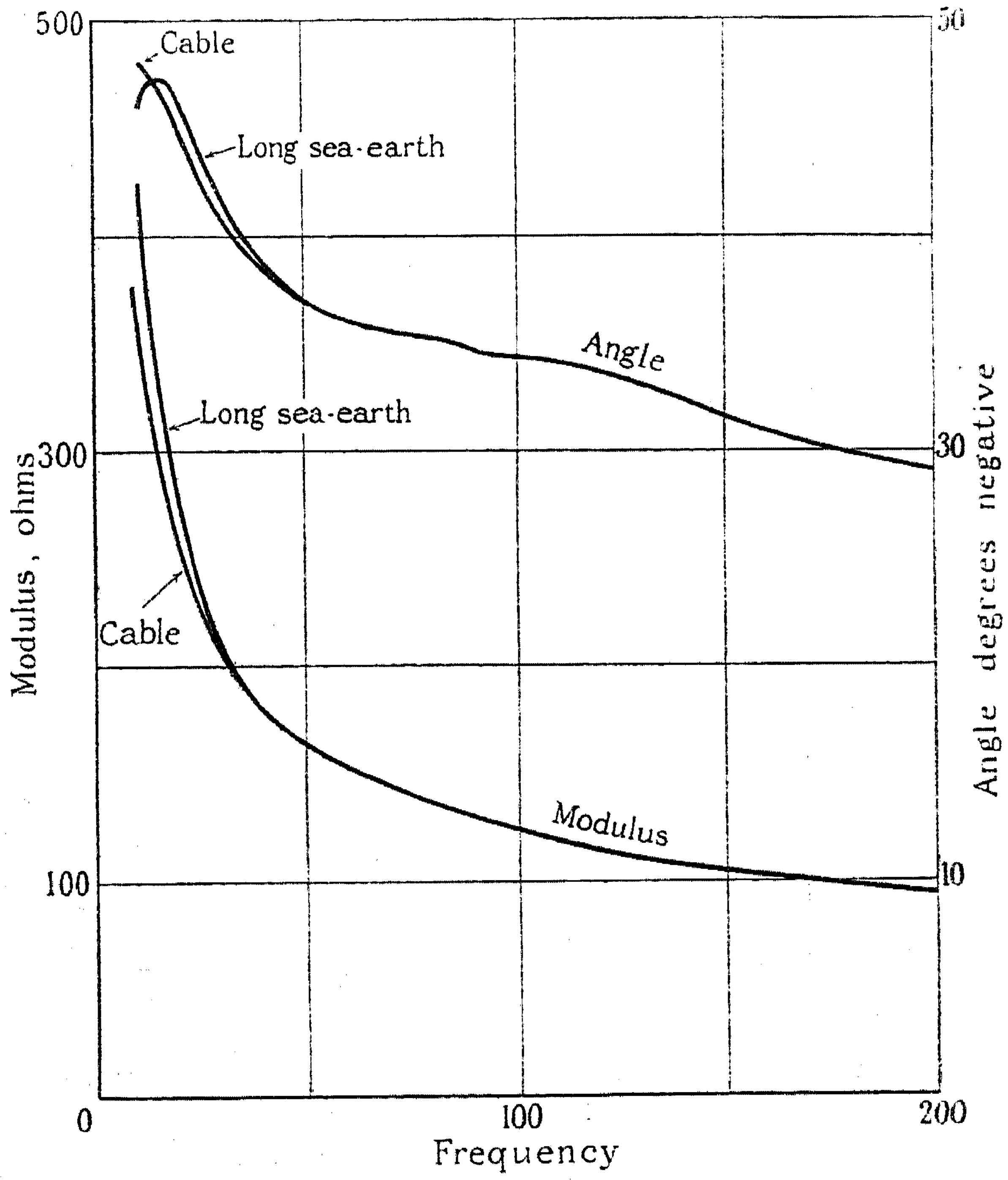

Fig. 1.—Impedance/frequency characteristics of cable and long sea-earth (148 nautical miles).

The simulation of the continuously-loaded cable by an artificial line, to the high degree of balance necessary for high-speed working on long submarine telegraph cables, has not yet been achieved.

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* The Papers Committee invite written communications, for consideration with a view to publication, on papers published in the *Journal* without being read at a meeting. Communications (except those from abroad) should reach the Secretary of the Institution not later than one month after publication of the paper to which they relate.

† A. E. Foster, P. G. Ledger and A. Rosen: *Journal I.E.E.*, 1929, vol. 67, p. 489.

Duplex loaded cables are not continuously loaded along their whole length. The shore-end sections are non-loaded for some distance from the terminals, and the inductance is " stepped-up " towards the centre of the cable where the loading is heaviest. These cables are said to be " taper-loaded."

The impedance/frequency curve of a taper-loaded cable is quite smooth and is constant for all values of the sending-end current (see Fig. 1). The reflection phenomenon manifests itself, not as a periodic departure from the characteristic impedance over the band of signalling frequencies, as in the continuously-loaded cable, but as a small decrease in the characteristic impedance. This is due to a number of factors, the most important being:—

(*a*) The absence of abrupt changes of impedance near the sending-end.

(*b*) The higher attenuation of the non-loaded cable as compared with that of the loaded-cable (see Fig. 2).

(*c*) The long length between the sending-end and the loaded section.

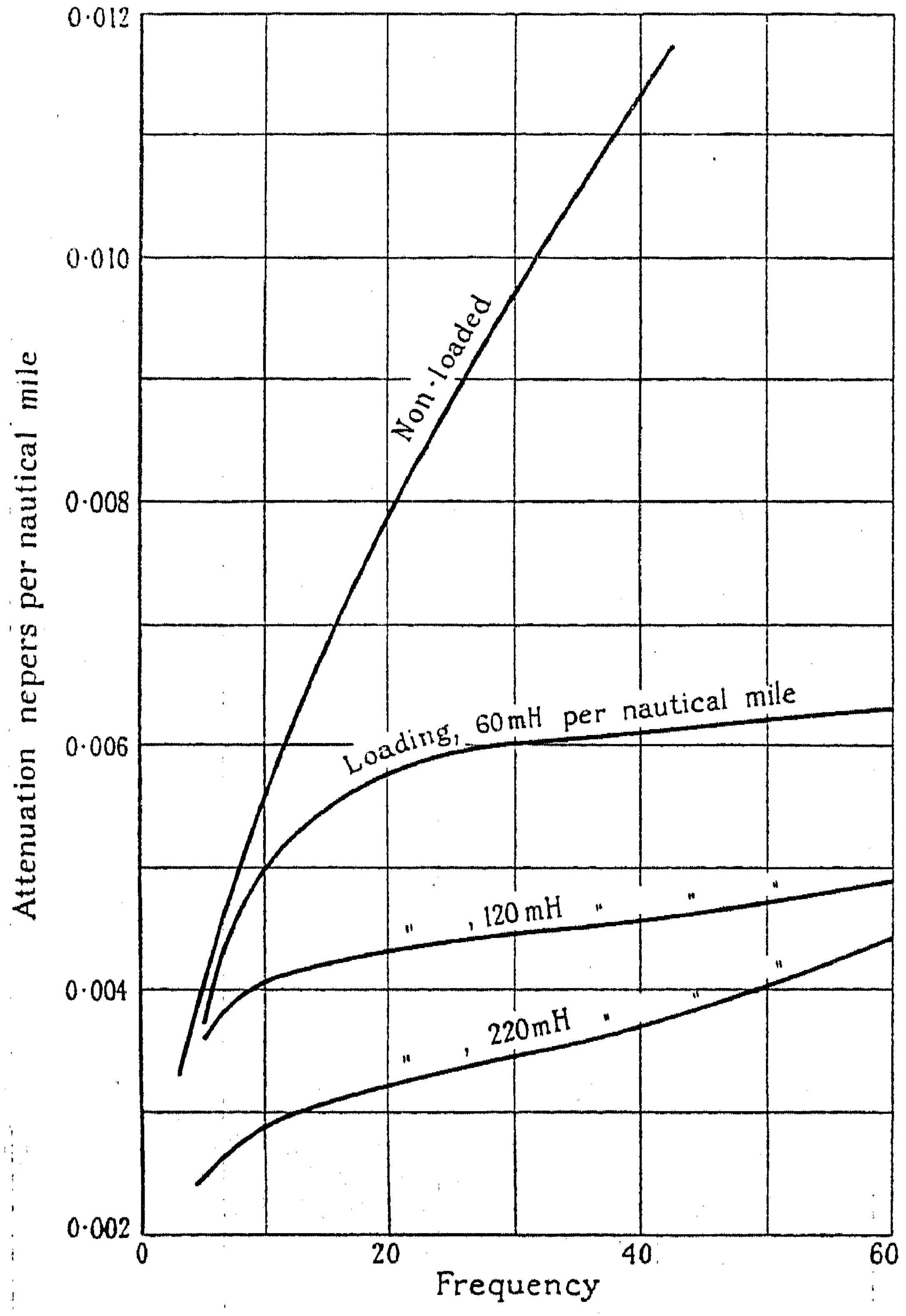

Fig. 2.—Attenuation/frequency characteristics of non-loaded and loaded cables.

Non-loaded core: 400-lb. copper conductor.
Loaded core : 225-lb. copper conductor.

(2) The Balanced Sea-Earth.

The speed of working of a loaded cable is limited by the amplitude and legibility of the received signals. Signal amplitude is governed by the overall attenuation, and legibility mainly by the quality of the duplex balance and the amount of extraneous interference.

The absence of large reflections in the taper-loaded cable makes the problem of the duplex balance much simpler than it would be for the continuously-loaded cable, and very high duplex speeds have been attained in practice with a high level of interference at the terminals. This has mainly been accomplished by the use of a " balanced sea-earth."*

Cables with " balanced sea-earths " have a twin core at their terminals, one core of which is connected to the sheathing wires at the seaward end through a length of stranded manganin-wire core and serves as an earth-return circuit for the artificial line.

Experiment has shown that interference of the higher frequencies is only present in shallow water, and it is for this reason that the sea-earth core is extended to a point where the cable enters deep water.

To obtain a high standard of interference elimination, the two cores must be carefully balanced as regards their electrical characteristics, and as far as possible the impedance of the manganin core must balance, over the range of signalling frequencies, the impedance of the cable seawards. The impedance of the short length of manganin core, earthed at its seaward end, is equal to its conductor resistance and is independent of frequency. The extent to which interference is neutralized by the balanced circuit provided by the sea-earth core is largely dependent on the value of this resistance. The resistance of the manganin conductor must be predetermined from data obtained from core tests in the factory.

(3) Determination of Value of Sea-Earth Terminating Resistance.

The characteristic impedance of a submarine telegraph cable is given (in ohms) by the formula

$$Z_0 = \sqrt{\left[\frac{R + j\omega L}{G + j\omega C}\right]}$$

where R = effective resistance, in ohms per nautical mile;
L = inductance, in henrys per nautical mile;
G = leakance, in mhos per nautical mile;
C = capacitance, in farads per nautical mile;
and $\omega = 2\pi \times$ frequency.

For a loaded cable where ωL is large compared with R, the characteristic impedance approaches $\sqrt{(L/C)}$ ohms at the higher frequencies.

Fig. 3 illustrates diagrammatically the balanced sea-earth of a taper-loaded cable, (*a*) with the earth termination in the non-loaded section, and (*b*) with the earth termination in the loaded section.

In Fig. 3(*a*), Z_0 has a large negative angle at all frequencies and its angle and modulus vary considerably with frequency. R_1 should balance, as nearly as possible, the impedance of the cable beyond the point B, at the critical or dot frequency, since interference due to unbalance at the lower frequencies is partly eliminated by signal-shaping apparatus at the terminal station.

The problem of determining the optimum value of the terminating resistance R_1 may be solved by considering the reflection at B. It may be assumed that the effect of the loaded section of the cable on the impedance at B is comparatively small. The reflected current at B is given by the formula:—

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* J. J. Gilbert: *Bell System Technical Journal*, 1926, vol. 5, p. 404.

$$I_3 = I_1 \frac{Z_0 - R_1}{Z_0 + R_1}$$

For simulation of Z_0 by R_1, I_3 must be a minimum.

I_3 is a minimum when $\frac{dI_3}{dR_1} = 0$.

Now $$\frac{dI_3}{dR_1} = \frac{d}{dR_1}\left[I_1 \frac{Z_0 - R_1}{Z_0 + R_1}\right]$$

Putting Z_0 in its complex form, $R_0 - jX$, we get

$$\frac{dI_3}{dR_1} = \frac{d}{dR_1}\left[I_1 \frac{R_0 - R_1 - jX}{R_0 + R_1 - jX}\right] = 0$$

Considering only the moduli:—

$$\frac{dI_3}{dR_1} = \frac{d}{dR_1}\left\{I_1\sqrt{\left[\frac{(R_0 - R_1)^2 + X^2}{(R_0 + R_1)^2 + X^2}\right]}\right\} = 0$$

$$I_1 \cdot \tfrac{1}{2}\sqrt{\left[\frac{(R_0 + R_1)^2 + X^2}{(R_0 - R_1)^2 + X^2}\right]}\left\{\frac{\left[(R_0 + R_1)^2 + X^2\right]\left[2R_1 - 2R_0\right] - \left[(R_0 - R_1)^2 + X^2\right]\left[2R_1 + 2R_0\right]}{\left[(R_0 + R_1)^2 + X^2\right]^2}\right\} = 0$$

whence $R_1 = \sqrt{(R_0^2 + X^2)}$.

Thus the optimum value of the terminating resistance is equal to the modulus of the impedance of the cable seawards.

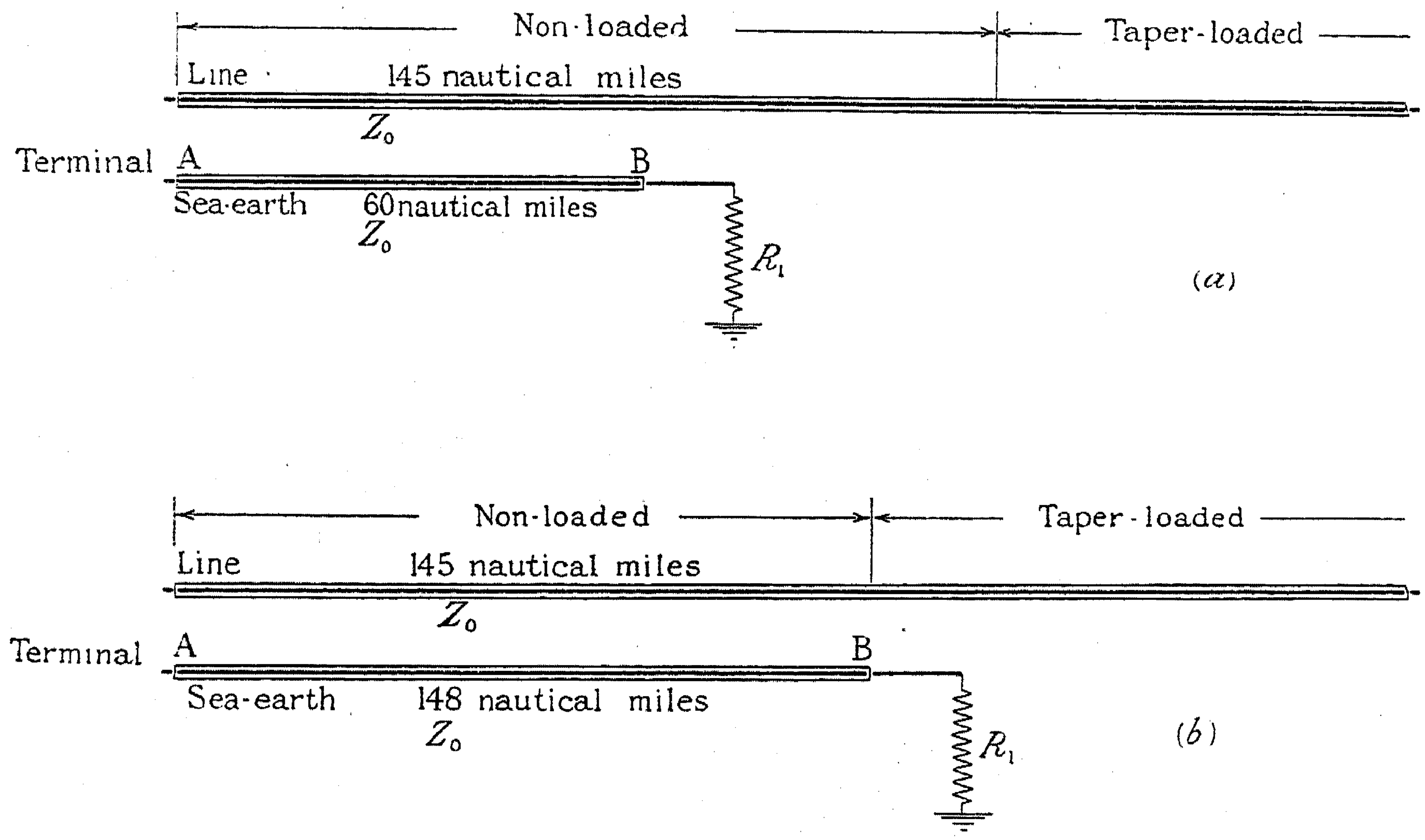

FIG. 3.

In Fig. 3(*b*), where the earth termination is in the loaded section, the problem is simplified. The impedance at B is almost a pure resistance for frequencies above 20. Fig. 4 shows how the characteristic impedance of a lightly-loaded cable (loading 60 mH per nautical mile) varies with frequency for a current of 1 mA.

(4) CALCULATION OF IMPEDANCE.

Referring to Fig. 3(*b*), the impedance of the taper-loaded section increases from point to point along the cable from B onwards, owing to the increasing added-inductance. The impedance at B will be affected by these changes of impedance along the cable.

Reflection occurs at each change of impedance, and when the changes are small the end impedance is given by the following formula, due to Rosen:[*]—

$$Z = Z_0 + Z_a e^{-2Pl_1} + Z_b e^{-2Pl_2} + Z_c e^{-2Pl_3} + \ldots \text{etc.}$$

where Z_a, Z_b, Z_c, etc., are definite increases of impedance at points distant l_1, l_2, l_3, etc., nautical miles from B. Each discontinuity can thus be considered separately.

From factory tests only the average inductance over lengths of 3 nautical miles is known, and it does not necessarily follow that the inductance is uniform over such lengths. The question arises as to how far the process of subdivision need be carried in order that the end impedance may be predicted to a fair degree of accuracy.

Formulæ due to Rosen[†] give the end impedance due to two types of irregularity, viz.—

(*a*) Where the impedance increases from Z_0 to $(Z_0 + Z_a)$ at a distance of l nautical miles from the end, and changes back to Z_0 at $(l + d)$ nautical miles from the end. For these conditions,

$$Z = Z_0 + 2Z_a e^{-2Pl} \sinh Pd$$

(*b*) Where the impedance increases to $(Z_0 + Z_a)$ at l nautical miles from the end, at $(l + d)$ nautical miles the impedance changes to $(Z_0 - Z_a)$, and at $(l + 2d)$ nautical miles the impedance changes back to Z_0. For these conditions,

$$Z = Z_0 + 4Z_a e^{-2Pl} \sinh^2 Pd$$

Dividing the impedance change in (*b*) by that in (*a*), we get

$$\frac{4Z_a e^{-2Pl} \sinh^2 Pd}{2Z_a e^{-2Pl} \sinh Pd} = 2 \sinh Pd$$

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[*] A. ROSEN: *Journal I.E.E.*, 1927, vol. 65, p. 990.

[†] *Loc. cit.*

Thus according to Rosen the limiting length for which the reflections will not add up is given by:—

$$d \not> \pi/(6\beta), \text{ i.e. by } 2 \sinh Pd \not> 1$$

Since αd is small for a loaded cable, $\sinh Pd = j \sin \beta d$. If $\sin \beta d \not> \frac{1}{2}$, $\beta d \not> \pi/6$ as before.

But wavelength $= 2\pi/\beta$

hence $d \not> \lambda/12$ nautical miles.

For light loading (60 mH per nautical mile), the wavelength is generally about 100 nautical miles at a frequency of 50, and one-twelfth of a wavelength would be about 10 nautical miles. In a case recently met with in practice the increase in inductance per nautical mile was 2 per cent, giving an increase of impedance of 1 per cent per nautical mile. In this case the change of end impedance due to reflection was so small that it was neglected.

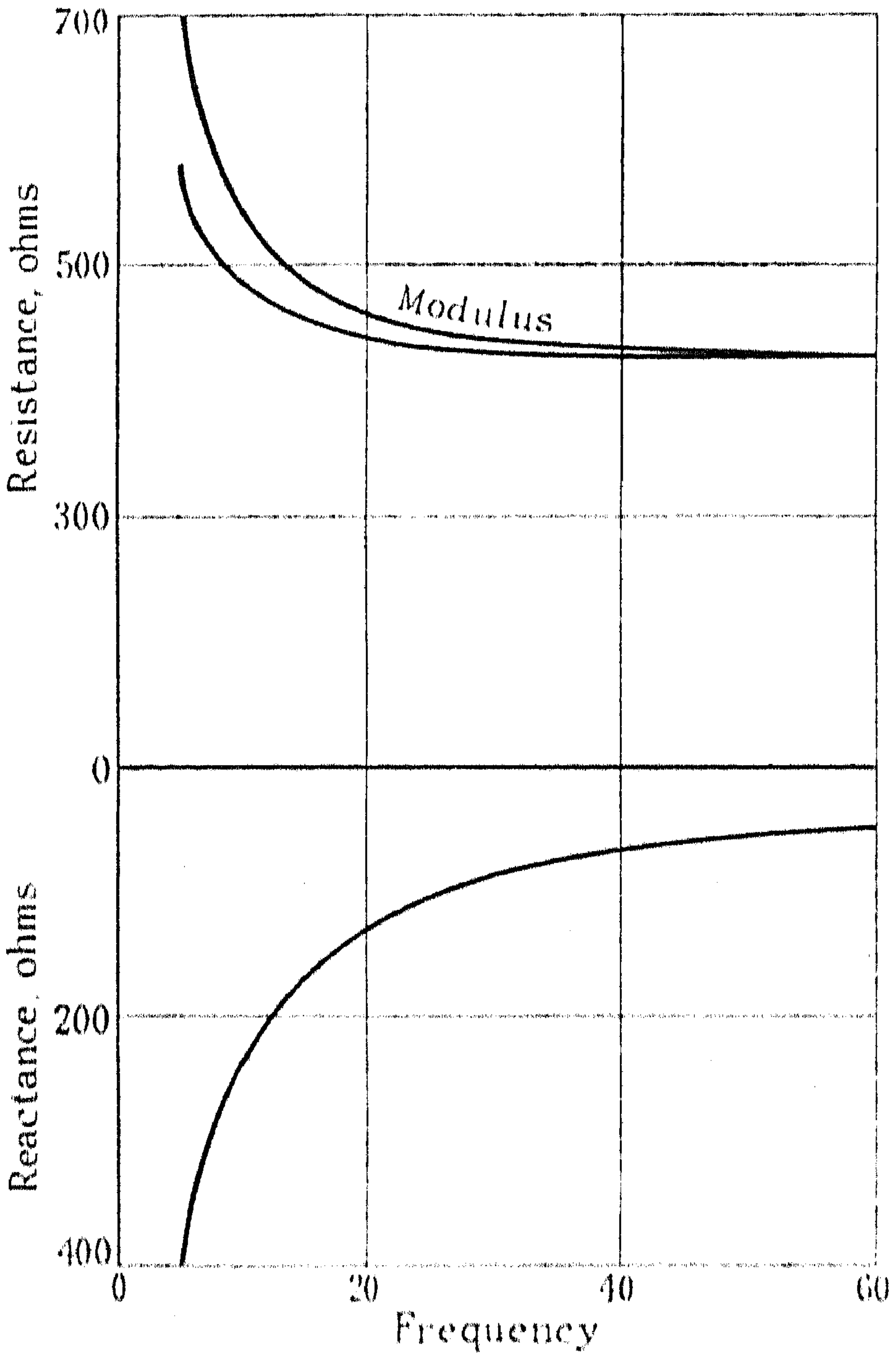

FIG. 4.

Referring to Fig. 3(a), the impedance at B is given by the formula

$$Z = Z_0 \left\{ \frac{Z_0 \sinh Pl + Z_1 \cosh Pl}{Z_0 \cosh Pl + Z_1 \sinh Pl} \right\} \quad . \quad . \quad (1)$$

$$= Z_1 \left\{ \frac{1 + (Z_0/Z_1) \tanh Pl}{1 + (Z_1/Z_0) \tanh Pl} \right\}$$

where l is the length in nautical miles from B to the junction between the non-loaded and the loaded section; Z_1 = end impedance of the loaded section; and Z_0 = characteristic impedance of the non-loaded section. In most practical cases Pl is large and only one reflection is significant. Formula (1) then becomes:—

$$Z = \frac{Z_0}{1 + 2e^{-2Pl}\left(\dfrac{Z_0 - Z_1}{Z_0 + Z_1}\right)} \quad . \quad . \quad . \quad (2)$$

where $(Z_0 - Z_1)/(Z_0 + Z_1)$ is of the form $| Z_r | e^{j\psi}$.

Therefore $Z = \dfrac{Z_0}{1 + 2 | Z_r | e^{-(2\alpha l + 2j\beta l - j\psi)}}$

$$2 | Z_r | e^{-(2\alpha l + 2j\beta l - j\psi)} = 2 | Z_r | e^{-2\alpha l} \underline{\backslash 2\beta l - \psi}$$

This is an impedance, the resistance component of which is given by

$$2 | Z_r | e^{-2\alpha l} \cos (2\beta l - \psi)$$

and the reactance component by

$$- 2 | Z_r | e^{-2\alpha l} \sin (2\beta l - \psi)$$

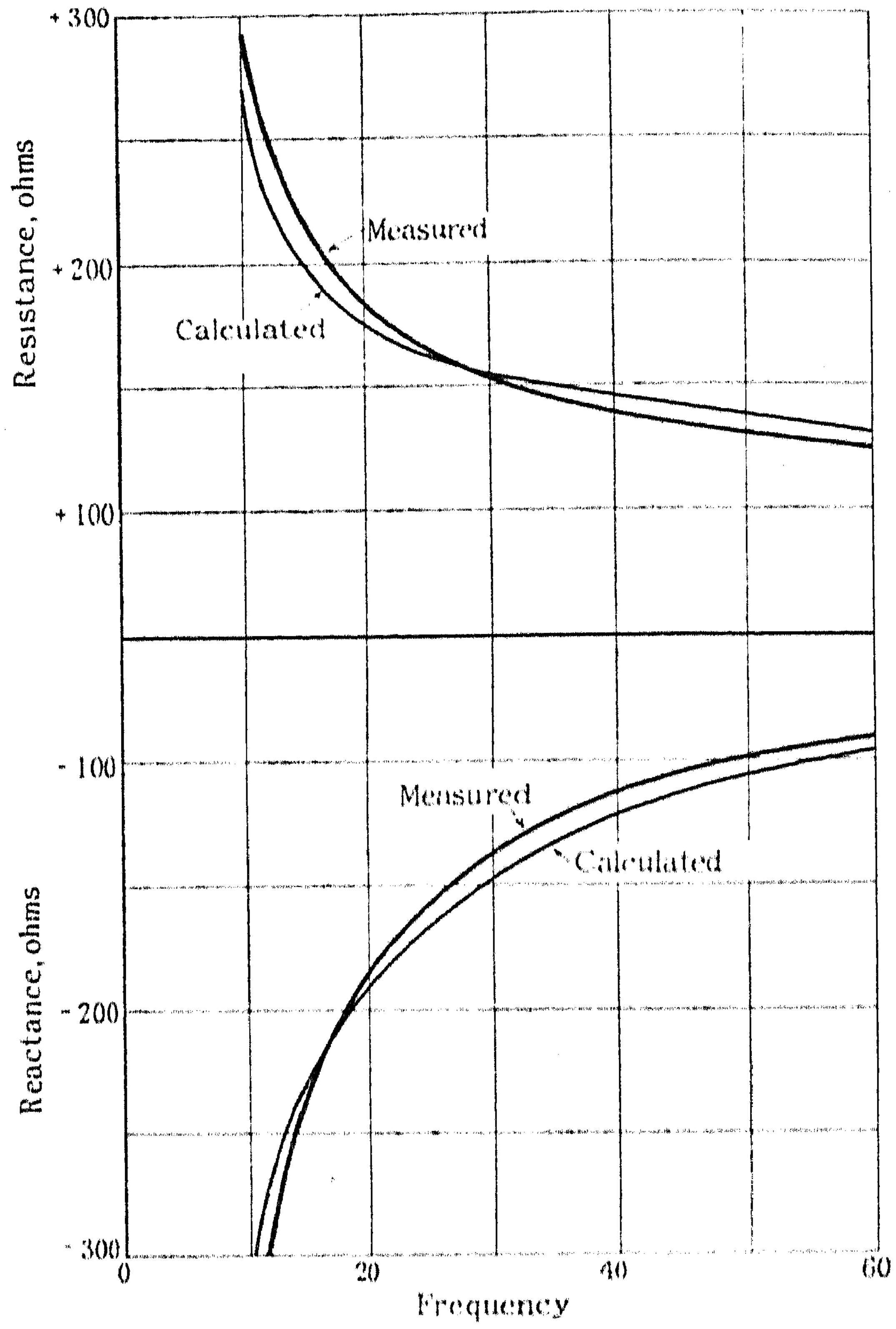

FIG. 5.—Impedance/frequency characteristics of long sea-earth (148 nautical miles).

Formula (2) is arrived at in the following manner:—

Incident current $= I_s e^{-Pl}$

Reflected current $= I_s e^{-Pl}\left(\dfrac{Z_0 - Z_1}{Z_0 + Z_1}\right)$

Reflected current arriving at B $= I_s e^{-2Pl}\left(\dfrac{Z_0 - Z_1}{Z_0 + Z_1}\right)$

The reflected current arriving at B is doubled by reflection, and becomes

$$2I_s e^{-2Pl}\left(\frac{Z_0 - Z_1}{Z_0 - Z_1}\right)$$

The reflected voltage arriving at B is suppressed by a reflection equal in magnitude and opposite in phase. The final impedance at B is then given by

$$Z = \frac{E_s}{I_s + 2I_s e^{-2Pl}\left(\dfrac{Z_0 - Z_1}{Z_0 + Z_1}\right)}$$

$$= \frac{Z_0}{1 + 2e^{-2Pl}\left(\dfrac{Z_0 - Z_1}{Z_0 + Z_1}\right)}$$

A comparison of the impedance value obtained from this formula with the value obtained from the standard formula will indicate whether more than one reflection is significant.

(5) Primary Constants.

The primary constants of the cable must be known to a moderate degree of accuracy before any calculations of impedance can be made. The four primary constants are effective resistance, inductance, capacitance, and leakance.

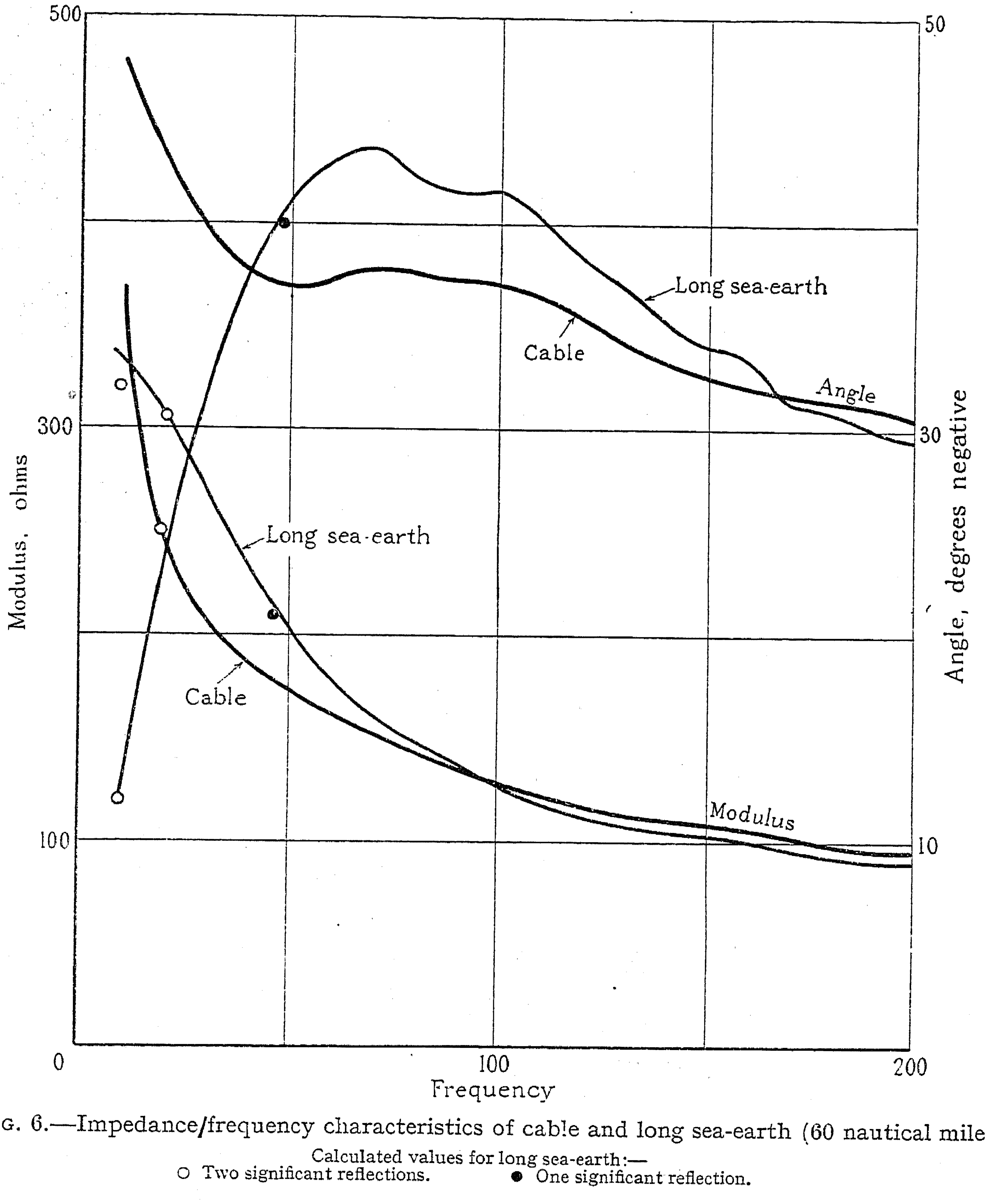

FIG. 6.—Impedance/frequency characteristics of cable and long sea-earth (60 nautical miles).

Calculated values for long sea-earth:—
○ Two significant reflections. ● One significant reflection.

Leakance can generally be neglected since it is relatively small at low frequencies. The ratio of leakance to capacitance for loaded cables in deep water is given by the empirical expression*: Leakance (G) $= 0\cdot018\omega C$ micromhos per nautical mile, where C is the capacitance in microfarads per nautical mile.

Effective resistance comprises the conductor resistance, added resistance and sea-return resistance. The conductor resistance can be obtained from core tests in water at 75° F. and must be corrected to sea-bottom temperature. The added resistance, due to loading, has two components, one due to hysteresis losses and the other to eddy-current losses in the loading material. The expression for added resistance at low current values is of the form

$$R_{ad} = Af + Bf^2$$

where f is the frequency and A and B are constants. Af represents the hysteresis-loss component and Bf^2 the eddy-current loss component. The constants A and B can be determined by plotting values of (added resistance)/(frequency) against frequency, the graph being a straight line. Values of added resistance can thus be estimated from factory tests for different grades of loading and currents below 10 mA. The sea-return resistance is given by the empirical expression: $R_s = 0\cdot005f$ ohms per nautical mile, where f is the frequency.

The inductance of a loaded cable comprises the added inductance, due to loading, and the natural inductance.

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* R. L. Hughes: *Journal I.E.E.*, 1928, vol. 66, p. 152.

The natural inductance depends on the dimensions of the cable and the number and type of the sheathing wires. Generally, it varies from 3 mH per nautical miles at 5 cycles per sec. to 1·5 mH per nautical mile at 60 cycles per sec. The added inductance can be determined from tests on the demagnetized core. A correction is applied for loss of inductance due to mechanical strain during laying. For deep-water cables factory values must be reduced by from 12 to 15 per cent, depending on the depth. Added-resistance values must be reduced accordingly on the assumption that the added resistance varies as the square of the added inductance. The variation of added inductance with frequency is small over the band of signalling frequencies.

Values of the capacitance can be taken from d.c. tests on the jute-served core during manufacture.

(6) Results in Practice.

Fig. 5 gives a comparison between calculated and measured values of impedance on a long balanced sea-earth, and shows that results can be predicted to within an accuracy of 5 per cent.

Figs. 1 and 6 are impedance/frequency curves of the cable and balanced sea-earths of a recently-laid cable. The balanced sea-earth of Fig. 1 is terminated in the loaded section, whilst that of Fig. 6 is terminated in the non-loaded section. The reason for the much better impedance balance shown in Fig. 1 is the degree with which a pure resistance balances the impedance of a loaded cable. The comparison of impedance shown in Fig. 6 gives for the sea-earth a modulus of 16 per cent and an angle 11 per cent above the corresponding figures for the cable, at 50 cycles.

The values of measured impedance are reproduced by courtesy of the Telegraph Construction and Maintenance Co.

APPENDIX I.

Measurement of Impedance.

The impedance measurements shown in Figs. 1 and 6 were taken with a parallel resistance-capacitance bridge shown diagrammatically in Fig. 7, the detector being a vibration galvanometer tuned to the test frequency. No variation of impedance was found for current values up to 180 mA. With the bridge ratio of 10 to 100 ohms, balance was obtained with the variable resistance approximately 10 times normal and the variable capacitance approximately $\frac{1}{10}$ normal. A correction was applied for a short length of underground cable between the cable office and cable house. The underground cable being short, it can be represented theoretically by a single T network. The resistance, inductance and capacitance of the line are small and its leakance is negligible. The impedance of the underground line is therefore the vector sum of the total resistance and the total inductive reactance, and its admittance is equal to the reciprocal of the total capacitance reactance. Calling the impedance Z_x and the admittance Y_x, we have

$$\text{Measured impedance} = Z + Z_x$$
$$\text{Measured admittance} = Y + Y_x$$

The expansion of these expressions gives the correction to be applied.

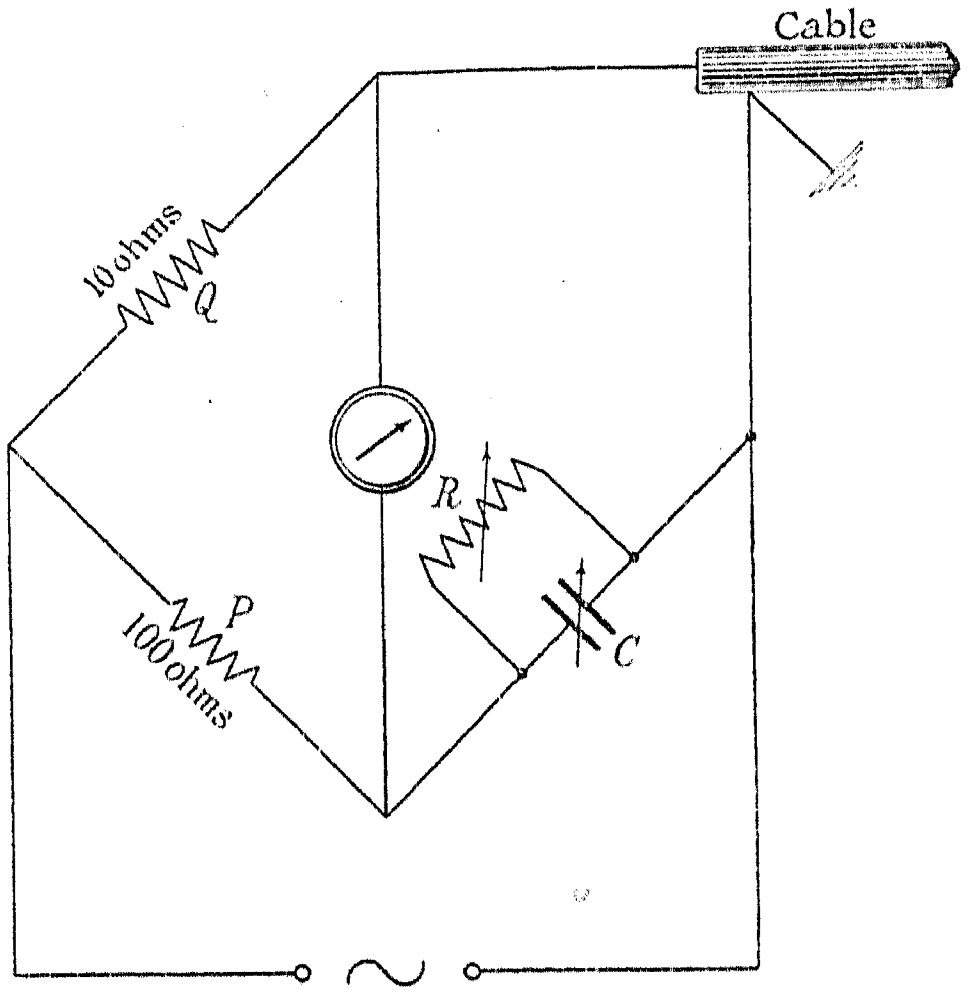

Fig. 7.—Impedance bridge.

$$Z = \frac{Q}{P}\left[\frac{R}{\sqrt{(1 + \omega^2C^2R^2)}}\right] \text{arc tan } \omega CR$$

$$Z = \frac{Q}{P}\left[\frac{R}{1 + \omega^2C^2R^2} - j\frac{\omega CR^2}{1 + \omega^2C^2R^2}\right]$$

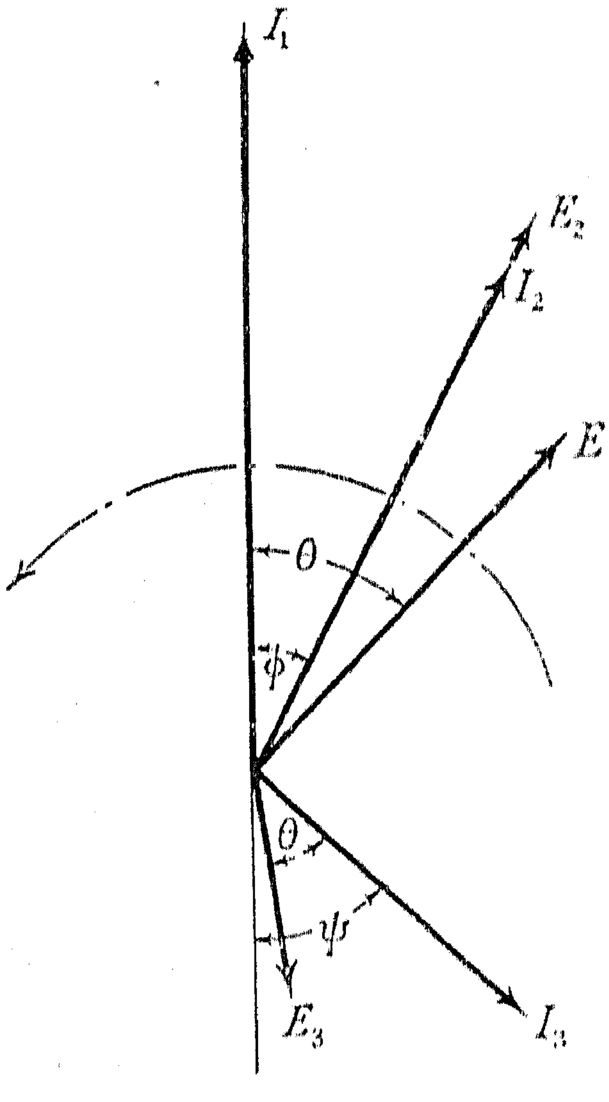

Fig. 8.

APPENDIX II.

A study of the reflection occurring at the junction between the non-loaded section and the loaded section or earth terminating-resistance is useful for application to impedance calculations. Fig. 8 is a vector diagram of the incident, reflected and resultant currents and voltages at the junction between the non-loaded and the loaded section at 25 cycles, calculated for a recently-laid cable. The current and voltage vectors are drawn to a different scale for convenience, and the angle of the impedance of the loaded section is taken as zero.

Complete expressions for the vectors are given by:—

$$I_2 = I_1 \frac{2Z_0}{Z_0 + Z_1} = I_1 Z' \overline{\backslash \phi}$$

$$I_3 = I_1 \frac{Z_0 - Z_1}{Z_0 + Z_1} = I_1 Z'' \underline{/ \psi}$$

$$E_1 = I_1 Z_0 \overline{\backslash \theta}$$

$$E_2 = I_2 Z_1$$

$$E_3 = I_3 Z_0 \overline{\backslash \theta}$$

NORTH-EASTERN CENTRE: CHAIRMAN'S ADDRESS

By A. G. Shearer, Member.

"THE DEVELOPMENT OF DOMESTIC AND RURAL LOAD."

(*Address delivered at* Newcastle, 26*th October*, 1931.)

General.

In view of the rapid and extensive development of generation and distribution of electrical energy by the national "grid" scheme, it would appear that some broad, comprehensive plan of directing the attention of the public to the more effective and general utilization of electricity for domestic and commercial purposes is required if the amount of electrical energy sold throughout the country is to increase at an economic rate.

Adequate Wiring of Consumers' Premises.

The subject of wiring is of great interest at the present time, as every branch of the industry is anxious to obtain adequate wiring in all classes of buildings so as to permit of greater use of electrical applicances. In the past, attention has been concentrated on recommendations for technical requirements rather than on how adequate wiring could best be provided. The Institution can take full credit for its share in the work of compiling the "Regulations for the Electrical Equipment of Buildings," which are recommended by so many supply undertakings for the guidance of electrical contractors and consumers.

In many of the older domestic installations facilities for the use of electrical appliances were not provided, and it is usually less costly to provide a complete installation at the beginning than to have to incur the expense of repeated extensions and alterations later.

In recent years an appreciable sum has been spent annually in providing automatic voltage-regulators to maintain the voltage at consumers' terminals within the specified limits, but in the older installations where the load has steadily increased as the cost of electricity and the price of lamps have fallen, the wiring has not been reinforced to cater for the additional load demand. Supply authorities and electrical contractors are alive to the position, and it appears necessary that they should schedule an "average" lay-out to meet the consumers' requirements and strengthen the wiring to carry the load. Where assisted wiring schemes are available a lead should be given as to what is regarded not merely as a minimum size of wires, but also as desirable sizes of wires. It is reasonable to expect that efforts for dealing with this situation will enlist the co-operation of all concerned.

Domestic Appliances.

General.—It should be the aim of those who are interested in the supply of electricity to domestic consumers to develop the demand for household appliances on such a basis that all branches of the electrical industry will be anxious to co-operate. The main difficulty in the complete electrification of the home is undoubtedly the heavy initial outlay for wiring and for appliances; this difficulty is being overcome to a very large extent by easy-purchase schemes.

In order to ensure the regular use of appliances owned by consumers it is essential that adequate facilities should be provided for the repair and maintenance of such apparatus either by an electrical contractor or by the supply authority. In view of the need for encouraging the more regular use of domestic appliances, it appears desirable to consider whether consumers should not be able to purchase or hire appliances having a relatively high annual consumption on more favourable terms than appliances having a low annual consumption.

The purchase of any new appliance should not involve the consumer in the cost of a wiring alteration or the changing of plugs or fittings. In the past the absence of adequate wiring facilities has been largely responsible for the limited use of electrical appliances.

Refrigerators.—Since the beginning of 1929, when the Food and Drugs (Adulteration) Act of 1928 came into force, the demand for refrigerators has steadily increased and greater interest is now being taken in the development of suitable sizes for the home. The cost of small refrigerators is at present too high to encourage their more general use, and manufacturers and buyers should co-operate in standardizing a suitable size at a reasonable price.

In view of the vital necessity for preserving food, the demand for cheaper refrigerating apparatus—particularly in the sizes suitable for hotels, shops, homes and restaurants—is bound to increase.

Air-conditioning Equipment.—The owners of theatres and cinemas have clearly demonstrated to the public the advantage to be gained by the adequate provision of treated air in large public buildings, and although at present the installation of air-conditioning plant is not compulsory for such buildings, there is no doubt that in the future the demand for such apparatus will rapidly increase, especially for hotels, business premises and factories.

Electric Cookers.—During 1930 the British standard cooker (in two sizes) was first brought to the notice of all interested parties, but since then very little has been heard of its acceptance as a standard. A considerable amount of progress has been made in the design of electric cookers during the last few years, and it is unfortunate that so many minor departures from the main features of the standard pattern are still being put forward by makers.

Many of the departures from the standard design can be regarded as trivial and unwarranted. If the electric cooker is to compete against other types—and in future the competition will not be less keen—it is essential that the selling price should be reduced to reasonable limits, and it is very difficult to expect any reduction in price while makers are still being asked to manufacture sizes other than those accepted as standard. The smaller type of cooker that was originally classed as portable apparatus has become immensely popular, as it undoubtedly caters for those consumers who do not require a standard cooker.

Thermal-storage cookers, in which a small continuous supply of energy creates heat, are now on the market and their progress will be watched with interest, as apparatus of this description may help towards the reduction in the cost of giving supplies to scattered areas. The main element is of 500-watt loading and there is also a booster element of similar capacity in the oven. The circuit is so arranged that the maximum load cannot exceed 500 watts. Thermal-storage cookers have been in regular use abroad for many years, particularly where the tariff is based on a maximum demand. Their use in this country could be encouraged by fixing an all-in rate which would include the hire charge and so save the expense of special metering.

Curves are published from time to time showing estimated or actual cooking loads on sections of networks supplying a number of cookers; supply authorities recognize that this type of load is desirable, particularly as the consumption for a standard cooker may be from 1 000 to 1 800 kWh per annum.

I am not aware that the specification for the British standard cooker contains any clause regarding the watts required to maintain the oven at any stated temperature. The question to be considered by the manufacturers of cookers when deciding the rate of heat loss from an electric oven operating at normal temperature is whether due regard is given to the requirements laid down on the one hand by the consumer for the cooking to be done at minimum cost and in minimum time, and on the other by the distribution staff for a better load-factor on the network.

Makers of domestic apparatus should aim at obtaining the maximum thermal efficiency consistent with cost, and when the average price per kWh of domestic load is considered it will be realized that improvements will have to be made in the heat insulation of electric ovens before the cost of obtaining the increased efficiency equals the value of the energy saved.

In a recent paper on "The Future Development of Electricity Distribution in Great Britain,"* Mr. Nichols Moore stated that it was reliably estimated that there are about 9 million gas cookers in use in Great Britain. There are great possibilities of increased revenue from this class of load, particularly when it is combined with a water-heating load. Assuming an average energy consumption of 700 units per annum for all sizes of cookers, every 1 per cent of the 9 million gas cookers that are replaced by electric cookers would represent an increased annual consumption of 63 million units.

IMPORTS AND EXPORTS OF ELECTRICAL GOODS.

During the past few years the Central Electricity Board has placed contracts with British manufacturers for the equipment of power stations, transmission lines and substations, for the "grid" scheme. When this work is complete the rate at which new plant and equipment of this description is ordered will rapidly decrease. British manufacturers should, in the meantime, give serious attention to the question of how best they can successfully compete with the imports of electrical goods and appliances.

The rate at which the lighting and domestic load has steadily increased during the last 10 years is evidence of the value of the material and appliances that will constantly be required in future, not only to meet the demands of additional consumers but also to replace obsolete apparatus. The value of the renewals and replacements per unit consumed is much higher for the lighting and domestic than for the power load.

The national electrical scheme is backed by British capital and the plant and equipment is of British manufacture; it seems illogical that the major portion of a the energy from the "grid" scheme should be used on domestic appliances of foreign manufacture, while our own industries are not even supplying their normal output.

HIRE PURCHASE.

To facilitate the wiring of domestic installations, particularly in rural areas, hire-purchase schemes are not only desirable but also absolutely essential if the rate of progress has to be increased.

A report on assisted wiring and the hire-purchase of electrical apparatus was issued last year by the Electricity Commissioners. The recommendations outlined in that report had in a number of instances been put into operation previously by many of the supply undertakings, with gratifying results. Many of the consumers were rather hesitant to adopt any scheme of payment by instalments, probably due to the fact that they were not accustomed to enjoy the use of anything until the purchase price had been fully paid. The general acceptance of such schemes by the consumers will lead to a material increase, not only in the number of consumers connected but also in the annual consumption, due to the greater use of domestic appliances.

ELECTRIC HEATING.

During the past few years considerable improvements have been made in the design and application of electric heating apparatus, and special attention has been given to the development of devices for automatic temperature control. One has only to consider for a moment the rate of growth of the lighting load with the increased efficiency of the electric lamp in order to realize what opportunities there are for increasing the heating load for domestic purposes and for commercial buildings, provided that heating appliances are also improved.

Facilities should be arranged for demonstrating to consumers the most suitable types of radiators for all purposes, and at the same time for showing how automatic temperature-control apparatus can be efficiently operated. Many consumers have formed an adverse opinion of electric heating owing to their having purchased either a size or a type of radiator entirely unsuitable for the purpose they had in mind. Experiments and research have enabled standards of comfort to be clearly defined, and comparisons of different methods of heating can now readily be made on a perfectly equitable basis.

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* Proceedings of the Annual Convention, 1931, of the Incorporated Municipal Electrical Association.

The advantages to be gained by providing heat insulation for houses and commercial buildings have been more fully discussed in America and on the Continent than in this country, though in recent years an appreciable amount of British research work has been carried out. The results of practical tests clearly demonstate the saving that can be obtained by heat-insulating the more exposed portions of buildings, and particularly where the temperature is automatically controlled. The cost of heating any building materially depends on the conduction losses of the structure; it is therefore of great importance to ensure that where electric heating is installed, care is taken to use it efficiently.

Where houses and showrooms are equipped with modern electrical apparatus for demonstration purposes steps should be taken to prove to consumers and others that electric heating is much more efficient and more easily controlled if exposed walls and ceilings are heat-insulated.

Electrical engineers have been watching with considerable interest the developments in the electric heating of buildings of all types. The cost of electric heating has been too high in the past to warrant its general adoption, and if electricity is to be more generally used in future for domestic and commercial buildings it may be necessary to consider whether any modification in tariffs can be made that will tend to increase the demand for the heating load. Most supply undertakings now offer a tariff of 0·5d. to 0·7d. per kWh for water-heating where such load is of long-hour duration. A similar tariff for homes and offices would encourage the use of low-loading electric heaters for continuous use throughout the greater part of the year, and would permit of the necessary temperature conditions being maintained by the use of additional heaters, at a lower maximum demand and consequent less cost to the consumer and to the supply undertaking.

During the exceptionally cold spell of weather in February 1929, the peak of maximum demand in certain undertakings where the demand is mainly residential had risen to an average of 20 per cent higher than the peak of the previous December, when the maximum value usually occurs. The adoption of a scheme of long-hour low-loading demand at a similar tariff to that for water-heating, would definitely reduce the peak load and increase the load factor.

Electric Storage Radiators.—There are two main types of electric storage radiators: (*a*) those which have a sufficient capacity for a period of 3 to 5 hours, and which are generally used to supply only a portion of the daily heating requirements; (*b*) those designed and rated to maintain normal output for a period of about 8 hours. Where favourable tariffs for thermal-storage types of apparatus are available, the use of apparatus of this description should be considered for the heating of schools, homes, offices and shops.

Where energy is used in thermal-storage apparatus for heating buildings, particularly where arrangements can conveniently be made for the whole or the greater part of the heating apparatus to be disconnected at the time of the system maximum load, it should be possible for supply undertakings to offer a more favourable tariff than usual for the remaining portion of the heating load. Tests made on the amount of heat required throughout the day show that the heating load can be practically disconnected during the afternoons, and thermal-storage radiators are therefore usually designed to give up their stored heat during the forenoon. If similar arrangements could be made to connect this load to the system during a portion of the period when the load is low—say, 11.45 a.m. to 1.45 p.m.—the usefulness of this apparatus could be considerably increased.

Storage radiators are in regular use on the Continent, where off-peak tariffs have been adopted. In view of its relatively low demand and high load factor this class of supply should be given more consideration as a base load for heating homes and commercial buildings, particularly as by means of a time switch it can be combined with the off-peak water-heating load.

Architects and builders should give more attention to the design of buildings that are to be electrically heated, than has been their practice hitherto. In future, the provision of heat insulation of walls and the automatic control of temperature will play a very important part in heating. Tests made on premises before and after the provision of heat insulation show that the latter is responsible for a saving of the order of 45 per cent.

WATER HEATING.

Domestic Consumers.—The problem of catering for the supply of hot water for domestic consumers is both interesting and complex. The consumer, on the one hand, requires an adequate supply of hot water at minimum capital and running cost and—as far as is practicable—free from restrictions; the supply undertaking, on the other, insists that if this class of load is to be given a low tariff, it must have a high load factor and preferably be disconnected at the time of the system peak load. On the Continent, supply engineers have given this subject very careful consideration and many interesting developments have been made. The progress of the water-heating load has been greater in Switzerland than in any other country. Domestic consumers there are able to take full advantage of the low-rate tariff for water heating.

The subject of water heating by electricity is being given very careful attention in this country, but the main difficulty up to the present has been the high capital cost of self-contained heaters, and the absence of any specially favourable water-heating tariffs. If rural electrification is to make the rate of progress now contemplated, the question of reducing the capital cost of apparatus having a high annual consumption will need to be seriously considered. So far as water-heating appliances are concerned, such facilities should be offered to domestic consumers as will enable them to make full use of existing cylinders and tanks, by equipping standard heating devices. Supply undertakings should be prepared to offer alternative tariffs and various types of equipment for sale or hire, because it is evident that, for some time to come, difficulty will be experienced in selling high-priced domestic appliances.

When one considers that in this country there are over a million homes already wired, one appreciates what immense possibilities there are for developing the water-heating load. There are many homes where, particularly during the summer months, facilities for obtaining an adequate supply of hot water at a reasonable cost would be welcomed. No other domestic appliance has such a high load-factor as the electric water-heater, and it is therefore particularly desirable that standard alternative methods of catering for the consumers' requirements should be available and appropriate tariffs arranged.

In order that the operating cost may compare favourably with that of gas for hot-water supply, electricity must necessarily be offered at a low tariff. This class of load offers great opportunities for load-factor improvement, and in those towns where special attention has been given to the development of the water-heating load the load factor has been considerably improved.

During the last few years several important undertakings have framed specially low tariffs for supplying water heaters of the thermal-storage type during a period of 8 hours overnight, and the question of allowing the supply to be taken at the same tariff during the period of the drop in the load about midday is also being seriously considered.

In future there will be only two classes of undertakings, namely those which purchase their electricity from the Central Electricity Board at "grid" tariffs, and those which purchase on the basis of adjusted station costs. In either case, the point to consider is what additional charge above that payable to the Board must be made to cover standing charges and the cost of units lost in transmission and distribution. It appears desirable that consideration should be given to three tariffs, namely: (*a*) one to cater for the thermal-storage type of heaters during a night-time period of 8 hours and for 2 hours about midday; (*b*) one to meet the requirements of thermostatically-controlled heaters that have a higher loading for a given capacity than those provided for under (*a*), and which will be automatically switched off at the time of the system peak; (*c*) one to deal with heaters of fixed loading that may be on load at the time of the system peak but which have a load factor of not less than 80 per cent.

Tests show that although the variation in the temperature of the water in the town mains is about 25 deg. F., the monthly consumption of electricity by water heaters is higher in summer than in winter.

As current will be switched on to night-time heaters usually for a definite period of 8 hours, the shape of the load curve in any portion of the system can be occasionally adjusted by staggering the time of switching for groups of consumers.

In Basle, of 8 200 kW of water-heating load 53 per cent of the heaters had an average connected load of 494 watts, while the remainder—varying in capacity from $16\frac{1}{2}$ to 440 gallons—averaged 3 956 watts. It is interesting to note that since the development of this load the time of minimum demand on the system has changed from early morning to 12.45 p.m.

Where the supply undertaking agrees to carry out the work of fitting elements to existing cylinders on consumers' premises, care should be taken to provide suitable lagging as this is essential for efficient water-heating. A hot-water supply could be provided in many of the smaller houses in rural areas by fitting heating elements of 175 and 265 watts in cylinders of 10 and 15 gallons respectively. No meter or time switch need be provided. The consumer would be charged a fixed rate per kW connected. The maximum possible annual consumption for these capacities would be 1 530 kWh for the 10-gallon size and 2 320 kWh for the 15-gallon size. The quantities of hot water (temperature 140° F.) available with small demands of this nature would be of the order of 17 and 25 gallons per day respectively, at a cost of 2·1d. and 3·2d. per day for energy at 0·5d. per kWh.

The three methods of thermal storage of energy in domestic installations which can be readily applied, to the mutual advantage of the consumer and the supply undertaking, are: (*a*) storage systems for hot-water supply; (*b*) storage radiators for heating buildings by other than hot-water methods; (*c*) cookers of the thermal-storage type. During week-ends it may be advantageous to extend the hours in which the low thermal-storage tariff operates.

Assuming that the average household can obtain a hot-water supply for 11 kWh per day, the annual consumption per 1 000 consumers would be increased by 4 million kWh if electric water-heating were adopted.

STANDARDIZATION.

During recent years considerable progress has been made in the standardization of the design and manufacture of all classes of electrical apparatus. Most users of domestic appliances will readily agree that there can be no real justification for so many variations in design, and one wonders whether the pride of the designer, the opinion of the purchaser, or the requirement of the consumer is given most consideration in this connection.

In order that the cost to the consumer may be reduced to a reasonable minimum, it is necessary for manufacturers of domestic appliances to agree on the most suitable design and cater for the greatest need. By "standardization" is meant not merely a simplification in the number of types and sizes and the securing of interchangeability, but also the adoption of standard specifications for the different types of apparatus. In addition, where it is agreed that it is in the mutual interest of the industry and the public, such recommendations should be observed in practice.

A reduction in the variety of sizes, dimensions, and immaterial differences in domestic appliances, in order to eliminate waste and reduce the cost of manufacture, will undoubtedly reduce the quantity and variety of stocks which must necessarily be held for service purposes, and should decrease the cost of production.

Considerable success has been achieved by the many engineering committees which have met to promote standardization in various branches of the industry.

The success of these committees is primarily due to the fact that there has been a co-operative spirit. Conflicting interests have come together, tabled their experience, and finally agreed to abide by the decision obtained.

INDUSTRIAL LIGHTING.

In recent years an appreciable amount of investigation has been carried out in this country and elsewhere to establish the most suitable lighting conditions for various specified purposes. In the future competition will be even keener than it has been in the past, consequently manufacturers will not be able to afford to operate their works without adequate and effective lighting, as higher standards of lighting are essential for efficient production. The importance of the rapid development in recent years towards cheapening and improving electric lighting for industrial purposes should encourage the management of industrial works to modernize their lighting installations.

The advantages of efficient lighting as regards plant output and the reduction of accidents ought to be more fully appreciated by those responsible for the management of industrial works. An appreciable amount of research has been carried out on the effect of higher intensities of illumination than those previously employed. Present practice indicates that higher intensities give rise to better workmanship and increased output. The reports issued by H.M. Inspector of Factories also regularly call attention to the need for better factory lighting, and to the relation between poor lighting and accidents. Insurance companies could, no doubt, readily furnish reliable information to show the rate of decrease of accidents consequent on the improvement in industrial lighting.

The need for better works lighting has for many years been generally recognized, and although many of the newer factories have had their lighting installations designed in accordance with modern practice, very little progress has been made with the older installations, though in recent years the delay has been largely due to the industrial depression. The cost of raising the standard of illumination in the older works can always be justified on the grounds of increased output and improved quality of the goods manufactured. As it is generally expected that in the near future the prosperity of our national industries will improve, the present time seems opportune for factory owners to consider whether there is waste due to improper design and choice of lighting fittings.

STREET LIGHTING.

The records of street accidents show that by far the greater proportion of fatalities occur during hours of darkness, and further, that in those thoroughfares the lighting of which is below normal, accidents occur more frequently; this is what one would expect. It is considered that about one-third of the accidents that occur during hours of darkness could be avoided if the thoroughfares were adequately lighted.

The need for uniformity in the lighting of our thoroughfares, as regards both intensity and diversity, was never greater than at the present time. The standard of illumination that was considered reasonable for the slow-moving traffic of bygone years is now inadequate. The rapid development in motor traffic has not been followed by like improvements in roadway lighting. It is not merely a question of what it costs to light 1 000 square yards of street, but the cost of providing over the given area the accepted standard of intensity of illumination.

Street lighting is being given more attention nowadays than it ever received in the past, due to it being regarded as an essential service and one that is justifiable in the interests of public safety. Public lighting engineers are fully aware of the amount of work that remains to be done to lessen the difficulties experienced by vehicle drivers; the main problems which confront them are the limitation of glare and the reduction of diversity. The former is probably the more important. The improvements obtained by the use of modern lamp-fittings show that the makers of the latter are alive to the many problems associated with the present-day requirements of street lighting.

Arterial Roads.—Many intricate problems have to be considered in connection with the lighting of arterial roads, and every assistance should be given to those engineers who are regularly carrying out tests in the interests of safety. Most of the accidents on main roads occur at or near crossings or junctions, and while it may be argued by the local authorities that a high standard of illumination cannot be justified throughout the entire length, there seems to be a case for high intensities at such crossings, provided that the transition from high to low intensity of illumination is gradual. The installation and maintenance of arterial-road lighting, of which crossing lights form a legitimate part, should be included in the initial cost of the road, and a portion of the Road Fund should be set apart annually for lighting purposes.

A considerable amount of discussion relating to the limitation of glare has appeared in the technical Press, and many interesting experiments have been made by public authorities. Where a limit between danger and safety has to be specified, however, objectionable glare is a quantity which it is clearly difficult to define. Street lighting is one of the commercial applications of electric lighting on which there has been the greatest difference of opinion regarding the standard of adequate illumination. The number of road accidents during hours of darkness diminish as the efficiency of the lighting increases.

Energy Consumption.—At present only about 50 towns have all-electric street lighting, and only about one-third of the street lighting in Great Britain is electric. The street-lighting load represents about 6 per cent of the units sold by authorized undertakings. The following figures give the annual street-lighting consumption of electricity in Great Britain during the last 9 years.

	Million units
1921–22	49·5
1922–23	58·6
1923–24	67·6
1924–25	78·3
1925–26	89·7
1926–27	96·4
1927–28	114·3
1928–29	127·8
1929–30	144·1

DEVELOPMENT OF DOMESTIC LOAD IN RURAL AREAS.

During recent years considerable attention has been given to problems associated with the provision of adequate supplies in rural areas. In many of the outlying districts of Durham and Northumberland supplies for domestic and industrial purposes have been in regular use for more than 20 years. The importance of developing such supplies has been emphasized by the Electricity Commissioners in their annual reports. It is interesting to observe that for the year ending 31st March, 1930, the average consumption per domestic consumer was of the order of 430 units in certain rural areas. Rural consumers are at present making little demand for electricity for heating, cooking and water-heating purposes. The fact that the annual energy consumption of average all-electric households is about 1 000 units for cooking and 3 000 units for water-heating reveals the immense possibilities of increasing the annual energy consumption per consumer.

Supply undertakings are constantly trying to reduce their capital expenditure on transmission and distribution for supplies to rural areas, and considerable improvements have been made in design. It is equally important, however, to keep a close check on the number of kWh sold per thousand yards of low-voltage distributing main.

Those whose duty it is to assist consumers in obtaining suitable appliances can help materially to reduce capital costs by so developing the load as to increase not only the load factor of the network, but also that of individual consumers. The problem of increasing the load factor of the domestic loads must receive careful attention if the cost of electricity is to be reduced. As the fixed charges form the larger portion of the total cost of giving a supply, the most practical way to reduce the total cost is by increasing the load factor. In particular in connection with heating loads, it is not uncommon to find instances where a smaller radiator of lower wattage, apart from being cheaper to purchase, is equally useful to the consumer, and is far more convenient to supply.

Experience has shown that where electricity has been installed for lighting, its use for other purposes has almost invariably followed. The Bedford rural electrification scheme is unique in one respect; that it is proposed to erect the low-voltage network and then canvass residents to take supply. This is a departure from the usual practice of first obtaining a sufficient number of consumers to justify the capital expenditure, and it will be interesting to see whether this change of policy will be fully justified. It is expected that at the end of the first 6 years, 75 per cent of the residents will be taking a supply averaging 700 units per consumer per annum.

The extension of supply to these areas has introduced new technical and economic problems in connection with the design, operation and maintenance of the transmission and distribution systems. When considering the electrification of rural areas, the value of continuity of supply must be balanced against the capital and maintenance cost of such reliability. A scheme which refuses to recognize the possibility of an occasional interruption must necessarily require a greater capital and running cost than one which allows for even a very small percentage of failures of supply.

In every rural district it should be the special duty of someone to see that all public buildings are adequately and efficiently lighted. Technical advice on work of this kind is appreciated by the consumers, and is an immense help from an advertising point of view. If a preferential tariff for such buildings could be arranged, the difference between it and the standard tariff could probably be regarded as a charge against advertising.

Developments in the construction of high-voltage lines and substations and also of low-voltage networks, have resulted in appreciable reductions in capital cost per kVA installed. Standardization in this respect is very desirable. In view of the running losses in distribution transformers, inefficient types should be replaced.

The mean load factor on the generating stations of authorized undertakings for the year ending 31st March, 1930, was only 33 per cent. During the last 9 years the revenue from domestic consumers has been greater than that from industrial consumers, and it would appear that in future we must continue to regard the domestic load as being the more encouraging. The energy sold in Great Britain to lighting and domestic consumers has increased from 564 million units in 1921–1922 to 2 344 million units in 1929–1930, i.e. more than 4 times in 8 years. It is estimated that there are at present about $3\frac{1}{2}$ million domestic consumers in Great Britain, and that approximately $7\frac{3}{4}$ million houses are unwired. The steady increase in the lighting and domestic load has had a stabilizing effect on electricity supply during the industrial depression, and all sections of the electrical industry are concerned in discovering how this type of load can best be developed more rapidly and economically. The necessary action depends to a very large extent on local conditions.

Domestic consumers should be made fully acquainted with the practical use of domestic electrical appliances and, in particular, it should be demonstrated how all heavy-current equipment can be used most efficiently. Lighting bureaux, where the services of lighting engineers are available to demonstrate the improvements in modern lamps and lighting equipment, have greatly helped consumers in obtaining increased efficiency from electric lighting installation.

Electrical engineers should carefully consider what measures can be efficiently taken to further domestic electrification. Where domestic tariffs have been reduced, the rate of development has been accelerated, and, following such reductions in tariff, an increased effort should be made to get consumers to use more appliances. Efforts are being made throughout the country to increase the night-time load, by offering a favourable tariff. Domestic consumers can thus benefit by taking load for water-heating and thermal-storage radiators. Special attention should be devoted to this important opportunity of increasing the consumption of electrical energy without adding to the capital cost or extending networks.

IRISH CENTRE: CHAIRMAN'S ADDRESS

By Lieut.-Colonel H. E. O'Brien, D.S.O., Member.

(Abstract *of Address delivered at* Dublin, *29th October*, 1931.)

At the outset of this address it will perhaps be worth while—particularly for the younger members of this Centre—to consider briefly the progress which has been made, more particularly for the purpose of emphasizing the very favourable position of electrical engineers nowadays in comparison with that occupied by their predecessors.

It is difficult to realize that little more than 40 years ago electric motors, electric light, electric trams, wireless, telephones, aeroplanes, motor-cars, internal-combustion engines, and many other commonplaces of to-day hardly existed so far as the mass of the population were concerned. The fundamental principles on which these developments were to be based were known from the work of Faraday who, by painstaking and methodical experiments with the crudest of apparatus, and without mathematical knowledge, laid the foundations of the electrical industry of to-day and also from the mathematical and experimental researches of Kelvin and many others. Even 30 years ago technical education was confined within narrow limits compared with those of the present day; textbooks were comparatively few, the technical Press was scanty both in numbers and in letterpress, and, save in a few particular instances, Great Britain was far ahead of all her competitors in scientific knowledge and engineering skill.

To-day pure science has made vast strides, many of the secrets of the fundamental constitution of the universe are in process of solution, and vast armies of research workers in science and industry labour in every country in the world. The technical Press and numerous scientific bodies broadcast the results of these widespread, patient, and accurate researches to every country and in every language, technical schools exist in practically every town, universities have multiplied and each now has its faculty of engineering, and although Britain no longer occupies her former outstanding position of pre-eminence in engineering, so far as her manufactures and the inventive power of her scientists are concerned she is probably still in advance of all other countries.

What has been the general effect on human life of this vast expansion of knowledge, and what part has the engineer—more particularly the electrical engineer—played in it? In effect the essentials of life remain the same, but its amenities have been increased almost beyond belief. The one outstanding factor of the last century which fundamentally affected the inter-relations of the human race was the development and acceleration of means of transport, a development which had an even greater effect than the invention of printing.

This development of transport was mechanical in character; steam power—by facilitating the intermingling of races, the rapid and easy transport of all sorts of materials and food products, and more particularly by the increase it permitted in the production and distribution of literature—produced modern civilization, accompanied by a great increase in the humanity of thought and a softening of manners.

Until quite recently electricity had played an indispensable but not the principal part in this development. The development of telegraphy and telephony was a vital factor in facilitating the increased speed of transport and the more rapid and wide dissemination of news and knowledge, in the first years of its development, from 1880 (the date of the invention of the incandescent lamp) onwards.

Heavy-current electrical engineering, on the other hand, had been chiefly used for increasing the amenities of life. In recent years the application of electricity in two widely different directions may profoundly affect the probable future of humanity. In one direction hydro-electric power and long-distance transmissions may result in desert areas becoming productive and inhabited; in the other the development of wireless telephony, television and the moving-picture industry may have a repercussion as great as that produced by the invention of printing or of the steam engine. We may indeed be on the verge of even more tremendous discoveries than those of the last 50 years; the means of effectively and cheaply storing electrical energy, the production of electricity by solar power whether thermal or tidal, even the direct generation of electricity from fuel, may be at hand.

Yet this vast development of science and engineering offers a very real difficulty to the young engineer or scientist standing on the threshold of his career. The field of knowledge is so vast, the mass of technical publications so great, that youth may well feel puzzled as to what direction to take and what target to select as the aim of its ambitions. At the outset of an examination of this difficult problem it will be well for the young engineer to keep certain considerations prominently in view.

The present age is one of specialization, and even among specialists the competition becomes keener and keener. The field of knowledge that has to be covered even in the specialist's career becomes formidably wide, so that few of us can hope ever to absorb more than a mere fraction of the sum of knowledge existent even in our own particular field. Thus there is a tendency for the vast majority of professional men to work within the range of a limited number of stereotyped facts, mainly absorbed during their student days and in their earlier years of practice. Ambition and scientific curiosity die or pass into a state of suspended animation, and eventually the new facts which are being constantly brought to light are apt to be disregarded or to become objects of indifference.

It has been remarked with truth that the research worker who hopes to make new discoveries will fail unless he possesses imagination as well as scientific attainments, for he must be able to conceive ideas of things as yet non-existent. In a somewhat analogous way the engineer who is ever more and more to control the great forces of nature for the benefit of his fellow beings must endeavour to obtain as complete a view as possible of the range of contemporary research in his own section of the profession. He must have some vision of the possible practical applications of the new discoveries.

The expression "he was before his time" is often used in an almost depreciatory sense, although it was true of every great engineer—Watt, Stephenson, Ferranti, Parsons, to name only a few. Therefore to the young engineer who is endeavouring to select some special branch of his profession, a determination to cultivate a habit of mind ready to grasp the possibilities of every advance in design and material is of the utmost importance. When high-speed steel was first introduced a few progressive engineers rapidly realized the possibilities of the invention and filled their shops with machines suited to the new steel as quickly as these were produced, but the vast majority of manufacturers lagged behind. After superheating for locomotives had been rediscovered by Garbe in Germany the locomotive world for years practically disregarded what had been done, yet now superheating is the rule. When the steam turbine was so far developed that the engineer of one of the largest power stations in the United Kingdom remarked:—"It would pay me better to have turbines, even if I had to re-blade them every year, than to have these"—indicating his huge cross-compound engines—such machines were still being installed by many engineers. The greatest and most successful manufacturing corporations of to-day and the greatest engineers of the past and of the present are those who have given these considerations their first attention.

Next to this determination to be one of, or at least in close touch with, the advance guard of progress comes the importance of a proper education.

The object of elementary education is to provide a foundation upon which the rest of education may be built. It is all-essential that this foundation should be sound. Present schemes of education tend to cater for those of more than average ability and to be too ambitious in regard to the ambit of subjects covered, with the result that the bulk of elementary school children acquire an incomplete knowledge of too many subjects. The ability to make simple calculations rapidly and accurately, to write a clear hand and to prepare a concise statement or description is essential for an electrical engineer, whether manual worker or technician. From the electrical engineering point of view elementary education fails unless it provides such ability, without which the young engineer is not likely to attain any measure of success..

Secondary education should have two objects; first to make the largest possible percentage of the whole into useful citizens, whatever their sphere of life, and, secondly, by elimination of the less intelligent to select a small percentage capable of benefiting by a course at a university or at one of the larger technical schools. It is obvious that whatever the scheme of government or state of society under which we live, 80 per cent of the population must spend their lives in manual labour or subordinate positions. A majority of all classes possess a mentality and intelligence which makes them incapable, not of assimilating facts, because that depends on memory, but of analysing or drawing logical deductions from what they have succeeded in memorizing. Secondary education for this large class will therefore require to be framed on very different lines from that intended for the more intelligent minority. The secondary education which will make these people into useful craftsmen and citizens should deal first with those subjects a knowledge of which is required for their domestic lives, and secondly with the vocational training for their life occupations. Nor must the training of the girls be regarded as less important than that of the boys, for not even an electrical engineer can give of his best without a comfortable home, which cannot be obtained without a competent woman manager however many labour-saving electrical devices it may contain. Secondary education is incomplete unless it includes some training in handicrafts, and in this connection a quotation of some remarks by Lieut.-Colonel Sir A. Wilson is apposite. He states:—"There is a noticeable tendency in current literature on educational subjects to extol and exalt a standard of living which is purely cerebral. It is the cause of much unhappiness and discontent. The glories of modern science, of all art, of architecture, and of music, and the compassionate arts of surgery, and even of medicine, depend ultimately on the use of our faculties—our eyes, our voices, and especially our hands. A purely intellectual standard of life entails misery, futility, and eventual decadence. Literary men, professors, thinkers, philosophers, preachers, teachers, and politicians, have their place in life, but skilled manual workers are the real creators of a civilization. If modern education insisted more on hands than brains, civilized man would be more independent and therefore happier, and less prone to believe that the individual has an indefeasible claim on his fellows in the person of 'The State,' independently of any services he may have rendered or be rendering to it. The results of the present system are for all to see—vast numbers of poverty-stricken intellectuals who cannot use their hands to any useful purpose; men unable to paint their houses or to effect even the simplest repairs, unable to understand what is wrong with the simplest mechanism and obliged to call upon a semi-skilled workman to perform the simplest task; women unable to sew or cook, or to look after children, and who are miserable because they cannot afford to pay for others to serve them." One cannot agree with the statement that skilled manual workers are the real creators of a civilization, though they play an important role in the scheme. Nevertheless the modern tendency to regard clerical occupations, however poorly paid, as something superior to and more desirable than manual work is wholly undesirable.

Probably everyone is agreed as to the advisability of some such educational policy as the above, but there are three powerful forces—the parents anxious for the child to be earning, the employer anxious for cheap labour, the tax-payer appalled at the cost—which always have opposed and always will oppose such a forward step.

When a youth enters his life avocation, whether it be agriculture, engineering, or some other industrial pursuit, a systematic effort should be made actually to teach him how to perform the operations of his business rapidly and accurately, how to handle his tools, and at the same time, in a limited number of cases, how to continue his theoretical training. In large industrial centres with big factories this presents no great difficulty, the principal obstacle being the expense to the employer. In practically all these cases provision is also made for combining the scientific with the general education of the intelligent minority, either by means of a technical school attached to the works or by making use of adjacent university or technical-school facilities. In the days when work started at 6 a.m. it was the custom to confine the theoretical instruction to evening classes. This placed a heavy strain on the physical strength of an adolescent youth, and it is now becoming the practice to excuse the student for a period during the day so as to enable him to continue his theoretical studies. Many years ago some of the large German engineering works segregated their apprentices in apprentice schools or special apprentice shops where, under the guidance of the most experienced and highly-skilled workmen, they learnt their trade and at the same time contributed to the commercial output of the shops. Since the War many factories have found it advisable to employ a well-paid supervisor of apprentices whose sole business it is to follow up each boy's career through the shops, seeing that he is not kept too long on any particular job, and generally helping and advising him throughout his apprenticeship. At least one large English electrical manufacturing concern has a complete system not only for selecting suitable apprentices from the applicants seeking admission to the works, but also for grading the boys according to ability during their progress through the shops and for continuing their theoretical education.

The problem of dealing with apprentices in this way is, however, very difficult in a small agricultural country like the Irish Free State where there are numerous small businesses each with from one to five apprentices. Here there is no solution other than the technical school, which must provide manual as well as theoretical instruction—an unavoidable handicap. It would be desirable to have legislation making it compulsory for the employer to allow his apprentices to spend two or possibly three mornings per week at the technical school, and making it equally compulsory for the apprentices to attend the school. While it is true that the Vocational Education Act of 1930 makes it compulsory for the employer to release his apprentices for both continuation and technical education courses without loss of pay, it appears that education committees are under no obligation to provide the instruction at other than evening classes. It is obvious that grave difficulties stand in the way of the course suggested above, and that in the future we must hope to effect the desired result through a progressive expansion of the outlook of employer, apprentice and parent rather than through legislation.

The apprentice problem is affected by the attitude of the trade unions, whose members not unnaturally see in the multiplication of apprentices an attempt on the part of the employer to obtain cheap labour, and a subsequent vista of unemployment. On the whole this is all to the good, provided that a definite and well-conceived plan exists for selecting from the mass of boys seeking employment in the skilled trades those whose intelligence is likely to enable them to become first-class workmen. There should be no room in any trade for the indifferent workman, and 7 years of ordinary apprenticeship is no guarantee of skill or intelligence.

For those who are destined to take their places in the higher ranks of industry a considerably longer period at the university and a wider range of subjects seems desirable: but such an extension of the period of university education will probably not achieve its object—that of producing young leaders of industry with a far wider range of knowledge than is usual to-day—unless employers co-operate in the scheme and allow such students "sandwich" periods of 6 months at a works. Unless some such plan as this is adopted the student may tend to lose touch with the realities of business, and either become an indifferent scientist or join the already overcrowded ranks of the teaching profession. Such an extended university career is necessary because many present-day engineering problems call for close co-operation between the engineer and numerous allied professions and sciences as well as with the consumer. Many cases arise which require the co-operation not only of several specialists but also of a leader having some knowledge both of the various sciences involved and of business, financial and manufacturing methods. The more extended type of education advocated above would tend to produce this class of engineer in greater numbers, and would meet a demand which is but partially satisfied in most countries to-day.

The commercial side of the electrical engineer's work also calls for some comment. About 100 000 students in the U.S.A. are to-day attending business courses at the universities. There is no doubt that the salesman and commercial manager in an electrical undertaking must have a sound but not too specialized knowledge of the principles of mechanical and electrical engineering; otherwise it is impossible either for the salesman to explain his products intelligently to the customer or for the commercial manager to judge of the probable merits of his technicians' products. In addition, both must have a knowledge of commercial methods, customs and principles superposed on a sound general education.

Among certain races there is a strong tendency to confine the technician and the commercial manager rigidly to their own respective spheres and to hope for a happy spirit of co-operation between them. However suitable this system may be to other countries, it is inherently objectionable to our own more individualistic temperament and leads to delay, procrastination and entanglement in formalities. The combination of technical knowledge and commercial ability in one person ality offers to the young engineer one of the widest and most remunerative fields of work, but he must realize that it is one for which he must commence to prepare himself comparatively early in his career.

To give an idea of what is being done in this connection in the U.S.A., it is worth while quoting from the investigations of Dr. Bowie:—" It comes as a surprise to a British observer to find how completely in the great universities of the east the business school is regarded as the recruiting depot for managerial staffs. The observer is first impressed by the enormous number of different subjects taught. The business school of New York University, which has just completed its 13th year of existence, offers a total of 213 classes, including only the business subjects and economics. This is, so far as I can ascertain, the most striking instance of proliferation, but the Wharton School of the University of Pennsylvania offers over 100 subjects.

" The general subjects, arranged in order of importance, seem to be accounting, distribution (including advertising and marketing), banking and finance, economics, transportation, public utilities, management, statistics, business law, foreign trade, insurance, and personal management. Each of these subjects may again be subdivided into a dozen or more sub-species, for specialization has been carried far—many think too far. One factor raising doubt of the wisdom of this extreme specialization is what an American would call ' the student reaction ' to it. Recent investigation has shown that more than half the undergraduates enrol in the general business course, and, where they do specialize, the evidence shows that only about one-third of them follow in their business careers the fields of specialization they chose at college.

" Practically all undergraduate courses extend over 4 years. The usual procedure is to devote half of that time to subjects fundamental to business, such as economics, English, geography, mathematics, natural science, political science, applied psychology, or history. The remaining half is devoted either to the general business course, or to one of the specialized fields enumerated above.

" By far the greater number of schools are undergraduate ones. A few, such as Harvard and Stanford (California), are purely graduate schools, while others combine the last undergraduate year with the first graduate year. The undergraduate schools also differ in the extent of time they give to purely business subjects. While some limit these subjects to the last 2 years, the majority distribute them over the whole 4 years.

" Apart from teaching methods, there is a constant endeavour on the part of American business schools to introduce their students to the practical realities of business. Co-operation with the surrounding business community has been consciously and, in the main, successfully developed. Study visits to selected industrial and commercial concerns are a regular feature of many courses. Each student prepares a report on the visit, which is later made the subject of a class-room discussion. In some cases business men are called on to lecture to the students. At the Wharton School responsible managers from outside present actual business problems to selected students, and at a later meeting they discuss the solutions the students suggest. But the most ambitious plan to give the student ' clinical experience ' is that first developed by the University of Cincinnati. Under this ' co-operative plan ' the student undertakes a 5-year course in which he spends half the time in the paid employment of a business establishment. Some 250 firms co-operate with the school and the student ' shuttlecocks ' between the school and the job every 4 weeks. In spite of the administrative difficulties involved, the plan is declared by impartial observers to be thoroughly successful.

" No one can visit these large American schools of business without feeling some misgivings on the industrial future of any country which lacks them. The excellent buildings, the modern equipment, the spacious libraries, the keen and enthusiastic staffs, and the host of eager students who crowd—and sometimes overcrowd—the buildings, are all evidences of vigorous growth. The tens of thousands of young men who leave them every year, carefully nurtured in the lore of business, will be our competitors. Can we afford to ignore the contributory strength of a trained personnel? The American university business school cannot be written off to-day as either a fad or an experiment."

The report of the British Committee on Education for Salesmanship goes far to confirm the necessity for including business courses in our educational scheme, but it is open to question whether the American methods are correct and whether such courses should not rather be far more limited in scope than indicated in the above quotation and should only be open to post-graduate students.

Assuming that the young engineer is equipped with determination, a sound education both of a general and a professional nature, and some business training, in what direction is he to turn for a career? Is it possible to give him useful advice on this subject? I believe that during his last year of training every young engineer, whether at the works or at the university, should be given the benefit of a talk with one of the leaders of his profession on the subject of his future. Such assistance indeed will amount to little more than a help up the first step of a long and laborious climb, but for the small trouble involved it is worth while.

The race is to the swift and the battle to the strong: the young engineer must largely depend on his own intelligence and strength, but he should reflect that while he inherently possesses these, he can look for a third qualification—experience—in two directions only, future time and his elders in the profession.

In any review of electrical progress for this Centre the question of a supply of energy for domestic purposes must take first place, as other developments, apart possibly from those connected with agriculture, are unlikely to be of an extensive nature. The electric cooker, refrigerator, washing machine, vacuum cleaner, and iron, have been brought, it is true, to a high pitch of perfection, but finality will not be reached until (*a*) the apparatus is more foolproof and requires far less attention than at present, (*b*) the price is considerably reduced, and (*c*) better service is given. Improved design will lead to reduction in service work, and this will help to diminish the first cost.

The widest use of domestic apparatus cannot be obtained without a hiring scheme. In the absence of such a scheme, however desirous the seller of the apparatus may be to give service, this is apt to be of a very unsatisfactory nature; whereas when the apparatus remains the property of the supply company service must be given. Nearly every large electricity undertaking now lets cookers and other apparatus out on hire, and in many cases such equipment is installed and maintained free of charge. One eminent borough engineer of wide experience goes so far as to say that it is sound business policy to let apparatus of this kind out on hire at a figure merely representing a return of the net capital outlay in 10 years, the undertaking bearing the cost of maintenance and loss of interest which is incurred through such a scheme. There is little doubt that the interests of the supply authority, the manufacturer and the consumer —in fact, of everyone except the retailer—are best served when the supply authority is the sole or main purveyor of the electrical apparatus made for domestic use.

The supply authority's main object should be to provide the electrical equipment for every house and farm in its area and to see that such equipment is used to the maximum extent consistent with the incomes of the occupiers. The great majority of such potential consumers have very modest incomes, so that to secure their custom standardized equipment must be supplied to them in some cases at the lowest possible price and in most cases at an extremely low annual hire charge. Electrical appliances can be both produced by the manufacturer and purchased by the supply authority in large numbers at incredibly low prices compared with those of similar apparatus marketed by the average retailer, whose legitimate field should be the sale of the more elaborate and ornamental apparatus demanded by the wealthier consumers. It is, however, of great importance that public supply authorities should be legally compelled to keep strictly separate accounts for the separate businesses of (*a*) generation of current, (*b*) distribution and sale of current, and (*c*) sales and rental of apparatus and the service connected therewith.

The system of tariffs adopted has a great influence on the progress of an electricity undertaking, and the importance of increasing the consumption of electricity during the off-load hours by offering very low rates is fully realized in England and on the Continent. The consumer in Ireland as yet knows nothing of the benefits to be obtained from electric cooking and water-heating at low rates per unit during restricted hours on apparatus obtained at a small rental, installed free of charge, and maintained by the supply authority.

The widest extension of domestic and rural electricity supplies can only be achieved under the management of an experienced and highly trained engineer and a board of business men accustomed to the financial control of large undertakings. The latter should be ready to take a long view, to spend money in order to make money, to take full advantage of the experience already gained by others, and to employ for some years a considerable staff of first-class salesmen, demonstrators and service men. This policy pays in the end, and undertakings in the U.S.A., Holland, and Great Britain, both private and municipal, are at present in advance of Ireland as regards their methods of salesmanship, organization and management.

To the Irish people the progress of the use of electricity in agriculture should be a matter of special interest. The two obvious and serious difficulties in the way of giving electrical service to the farmers are the high cost of the distribution system—owing to the small density of population—and the poor load-factor obtainable, both of which tend to remove the principal attraction of electrical service in the shape of a low price per unit. To these two principal difficulties must be added a third and fourth—the natural conservatism of the agriculturist and the almost prohibitive cost, at any rate to the small man, of the installation.

There seems to be only one possible solution to this problem of cheap supply to sparsely-inhabited agricultural districts, namely, the total abandonment of the 220-volt distribution network and the substitution of an 11 000-volt system of rural feeders with small transformers connected directly to individual consumers' installations. The small 3- to 5-kW transformer is already being developed for this purpose and with further operating experience and increased demand for the apparatus there will be a considerable field for this system, which carries with it the great advantage of making it possible to use a very low voltage on the consumer's premises, thus greatly diminishing the chance of breakdown and risk to life.

The following example enables a comparison to be made between agricultural conditions in the U.S.A. and in Ireland. The Puget Sound Power and Light Co. serves an area of 30 000 square miles, of which only about 8 per cent is farmed, and in this area over 3 200 miles of rural distribution lines serving 20 000 out of 40 000 farms in the territory have been constructed. The average-size farm is of about 36 acres, and the total annual value of the agricultural products of the area is about £16 000 000. This represents about £400 per farm or about £11 per acre, a much higher figure than is obtainable in Ireland. The average consumption by the farm customers in 1928 was 1 457 units, costing £11 per annum or about 1·8d. per unit. The principal products marketed were milk, poultry, apples, and hay. The large amount of irrigation which is carried out in that part of the U.S.A. accounts for about 30 per cent of the energy consumption, but if there is no need for irrigation in Ireland there is plenty to be done in the way of drainage. The State of Washington has, however, a much more favourable climate than has this country. Though this and many other illustrations which might be given show that the use of electricity is making headway among farmers, it is evident that the methods of salesmanship adopted have a profound influence on the rate of expansion in rural areas. The act of throwing a sprat to catch a mackerel must be frequently and judiciously performed.

Apart from what may be described as the use of electricity for general farm utility work, much remains to be done in the way of special supplies for such purposes as poultry farms and hot-beds for the intensive production of early vegetables and mushrooms. We have yet to see established in Ireland all-electric poultry farms on the scale of that of the Buttercup Dairy Co. in

Edinburgh,* which covers 86 acres and owns 200 000 laying hens. This farm, which is using about 1 500 000 units per annum, has recorded a mean load of 860 kW and an approximate load factor of 20 per cent.

In conclusion, I should like to put forward a plea for closer co-operation between the scientific societies of Ireland. I also suggest that Ireland's engineering problems should be dealt with by Irish—as distinct from foreign—experts.

* See *Journal I.E.E.*, 1931, vol. 69, p. 58.

INSTITUTION NOTES.

British Standards Institution.

A Supplemental Royal Charter has been granted to the British Engineering Standards Association authorizing the change of the title of the Association to "British Standards Institution."

Papers on Radiology.

The Council have appointed a special Technical Committee to obtain papers on radiological and electromedical subjects, and to deal with such other matters as may be referred to it by the Council. The aim is to stimulate and foster interest in the electrical engineering aspect of radiology. The Committee, which is representative of electrical engineers, medical men, and radiographers, is at present engaged in obtaining papers on the above subjects for reading before the Institution during the session 1932–33 and subsequent sessions.

Coopers Hill War Memorial Prize and Medal.

The triennial award of the above prize and medal, which fell in 1931 to the Institution, has been made by the Council to Dr. M. G. Say, M.Sc., Associate Member, for his paper on "High-Voltage Underground Cables."

Informal Meetings.

139th Informal Meeting (26th October, 1931).

Chairman: Mr. J. M. Donaldson, M.C. (President).

Subject of Discussion: "Is the Engineer given his Due Share in Management?" (introduced by the President, Mr. J. M. Donaldson, M.C.).

Speakers: Messrs. E. S. Byng, J. F. Shipley, P. Dunsheath, O.B.E., M.A., D. A. Stewart, F. A. Cobb, W. Lang, S. B. Jackson, D. J. Bolton, M.Sc., W. A. Moore, S. C. Bartholomew, J. W. Rissik, E. S. Ritter.

140th Informal Meeting (9th November, 1931).

Chairman: Dr. A. Rosen.

Subject of Discussion: "Lightning Protection, especially in Tropical Countries" (introduced by Mr. J. F. Shipley).

Speakers: Messrs. J. Urmston, S. B. Jackson, M. Whitgift, K. L. Wood, P. Stevens, W. J. Minton, A. W. Evans, B.Eng., F. E. Wallcroft, W. Bibby, A. G. Hilling, H. M. Lacey, B.Sc., A. J. Cridge, J. F. Perrin, G. F. Burridge, W. Lunn, E. S. Ritter, Dr. A. Rosen.

141st Informal Meeting (23rd November, 1931).

Chairman: Mr. J. F. Shipley.

Subject of Discussion: "The Electrical Heating of Buildings" (introduced by Mr. R. Grierson).

Speakers: Messrs. A. Morgan, D. J. Bolton, M.Sc., J. Lesser, J. M. Kennedy, W. R. Rawlings, W. G. C. Jackson, D. A. Stewart, H. M. Proud, C. Davidson, H. C. Hazel, H. T. Young, J. R. Bedford, R. Mines, A. G. Hilling, J. Plummer, H. Bright, G. Wilson (communicated).

142nd Informal Meeting (7th December, 1931).

Chairman: Mr. W. A. Ritchie.

Subject of Discussion: "Improving the Reliability of Domestic Electrical Equipment" (introduced by Mr. C. F. Mounsdon).

Speakers: Messrs. A. Morgan, W. J. Minton, D. A. Stewart, P. P. Wheelwright, F. C. Raphael, M. Whitgift, G. G. Blake, J. J. C. Bacon, J. F. Shipley, A. G. Hilling, G. F. Bedford, E. P. Jones, A. F. Harmer, W. L. Wreford, J. R. Bedford, H. M. Ackery, R. Mines, W. A. Ritchie.

Membership Transfers.

The following transfers have been effected by the Council:—

Student to Graduate.

Advani, Bhagsing Tolasing.
Akister, Frederick.
Albutt, Edwin.
Brooksbank, Robert James, B.Sc.
Brown, Andrew, B.Sc.
Choudhuri, Surendra Nath, B.Sc.(Eng.).
Fawcett, Francis Alfred, B.Eng.
French, William Leslie M.
Hornby, James Hobson.
Houlgate, Henry John.
Jhangiani, Moti Gaganmal.
Knott, Harry Cleal.
Leighton, Gordon Loftus, B.Sc.Tech.
Lenton, Herbert Savery.
Lofthouse, Wilson Oswald.
McWhirter, William Alexander J.
Miller, John.
Moores, Bernard John.
Nagel, Llewellyn.
Panter, Charles Hugh.
Schofield, William Smith.
Simpson, Maurice Henry.
Smith, George Ernest.
Soutter, Cedric Guy, B.Sc.(Eng.).
Stowell, Peter d'Eyncourt, B.Sc.(Eng.).
Terry, Leonard George R.
Varma, Hans Raj.
Warbrick, Cecil.
Whiteside, Harold, B.Sc.
Woodhouse, Lionel Clayton, M.A.

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Proposed purchasing specification for yellow varnished cotton cloth and strip or tape. Ref. A/S21.
Performance tests on moulded lampholders. Ref. B/T9.
Heating of three single buried cables in triangular and flat formation. By the Director of Research. Ref. F/T31.
The detection of transient arcs in metal-clad fusible cut-outs. By P. D. Morgan and H. W. Baxter. Ref. G/T45.
The pressures produced on blowing electric fuse links: the effect of the surrounding atmosphere. By G. Allsop and P. B. Smith. Ref. G/T46.
The distribution of energy liberated in an oil circuit-breaker; with a contribution to the study of the arc temperature. By C. E. R. Bruce. Ref. G/XT19.
The prevention of trouble due to aquatic growths in condenser systems, with special reference to the destruction of mussels. By D. V. Onslow. Ref. H/T15.
The coefficients of heat transfer from tube to water. By A. Eagle and R. M. Ferguson. 8vo. Ref. H/T16.
Report of the Second International Steam Table Conference held in Berlin, June 1930. Ref. J/T70.
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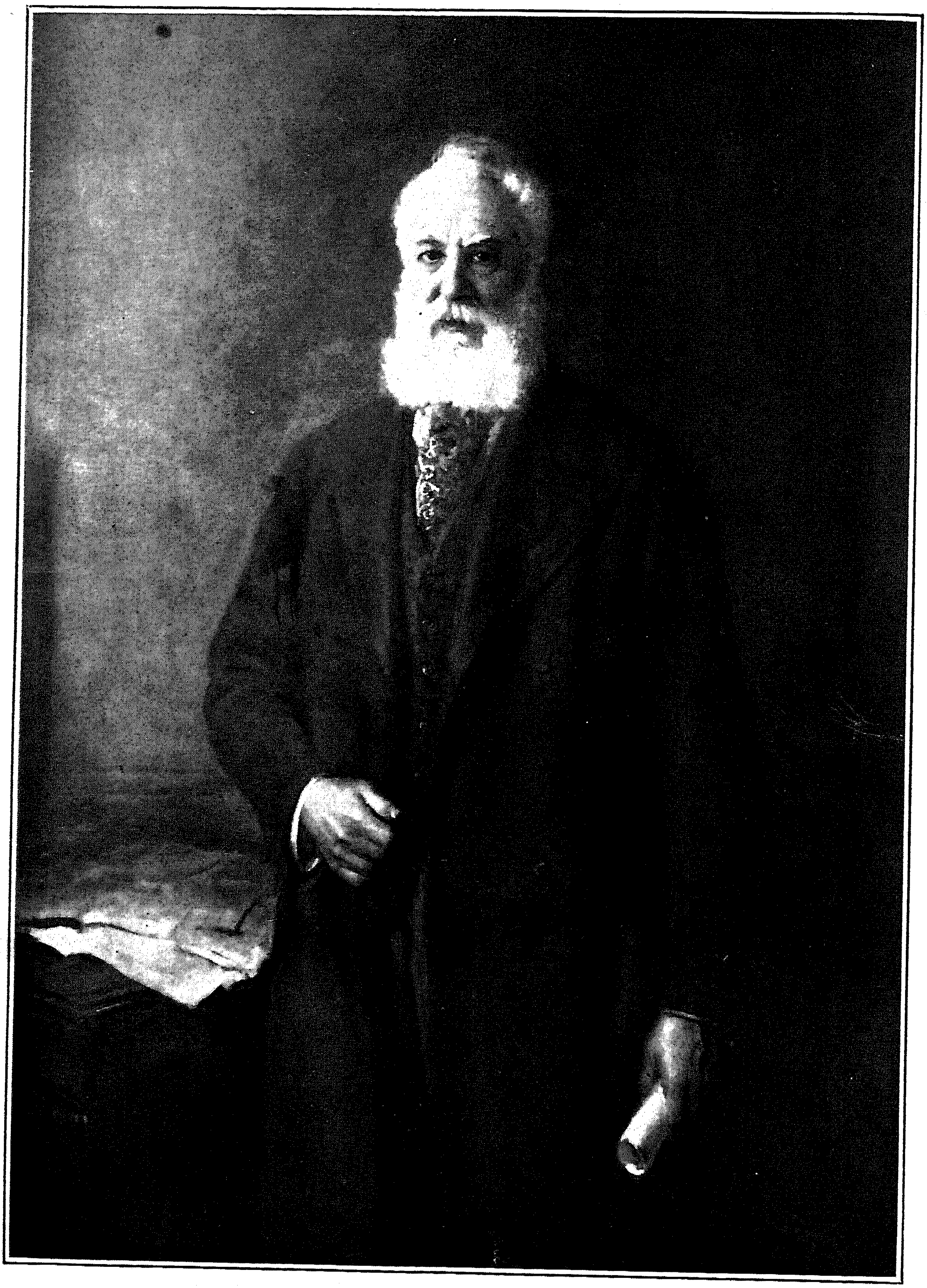

GRAHAM BELL. 1847-1922.

PAINTED BY W. W. RUSSELL, R.A., 1930.

PRESENTED TO THE INSTITUTION OF ELECTRICAL ENGINEERS
BY SIR HUGO HIRST, BART., 1931.

THE DESIGN OF A DISTRIBUTION SYSTEM IN A RURAL AREA.

By E. W. Dickinson, Member, and H. W. Grimmitt, Associate.

Paper first received 16*th April, and in final form* 23*rd September*, 1931 ; *read before* The Institution 19*th and* 26*th November, before the* Tees-side Sub-centre 5*th November, before the* Western Centre 9*th November, before the* Scottish Centre 10*th November, before the* Sheffield Sub-centre 18*th November, before the* North-Eastern Centre 23*rd November, before the* North-Western Centre 24*th November, before the* Mersey and North Wales (Liverpool) Centre 7*th December, and before the* Irish Centre 17*th December*, 1931, *also before the* South Midland Centre 18*th January*, 1932.]

Summary.

The present stage of rural development is reviewed and the general considerations affecting design of equipment are discussed. It was realized that an examination of the design of a concrete scheme would unduly limit the scope of the paper, and consequently an abstract scheme embodying average conditions found within Great Britain was employed. This was termed a "Model Scheme" and covered 400 square miles.

Average conditions, including those of average density of population (150), average load and average revenue, were sought and determined. Such information having been acquired, the general and then the detailed design are discussed, involving the construction of overhead lines and substation equipment best suited to the purpose, having regard to the limits imposed by financial considerations.

Estimates of capital expenditure and revenue over a period of years are given for the "Model Scheme," supplemented by estimates of similarly devised schemes based on densities of 100 and of 75 people per square mile, such densities being representative of the countryside.

Based on such statistics and data as are now available, and on a satisfactory tariff, the paper shows that electrification of sparsely populated rural areas is a practical proposition from a technical and financial aspect.

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(1) Introduction.

The time appears to be opportune for a review of the problem of rural electrification on a broader basis than in the past. Much pioneer and development work has already been done by enterprising companies and local authorities, and by supply engineers who, to their credit, have, in the intervals of keeping pace with growing loads on their generating stations and their urban distribution networks, found time to devote considerable thought and energy to the question of distribution to potential consumers in the more distant portions of their areas of supply.

The design of rural electrification systems, as now erected, shows, as might be expected in the early stages of development of this kind, considerable variations, due first to differences in comprehension of the general problem, secondly to diversity in cost of electricity at power stations, and thirdly to the means taken to surmount the physical and financial difficulties presented. The varied experience and pioneer work have been invaluable and point the way to further considerable development on a more standardized and a more economic basis than hitherto.

The progressive extension of the "grid" by the Central Electricity Board will, within a few years, bring into existence a system whereby electricity can be delivered at a reasonable cost to all authorized undertakers at one or, perhaps in the case of large areas and with the co-operation of the Board, at two or more convenient points within their areas.

The cost of bulk supplies will then be more uniform than hitherto; there are indications that such uniformity and lowered cost may result shortly in such agreed terms as will make the financial results of rural electrification more certain and make possible an extension of the radius of economical development. Relieved more and more from the anxieties of generation supply engineers will, as time goes on, be able to direct attention increasingly to the important problems of distribution and to the kind of service organization needed for the efficient *sale* of electricity.

TABLE 1.

Year	Total capital expenditure 1	Capital expenditure (generation) 2		Capital expenditure (distribution) 3	
	Millions of £	Millions of £	Per cent of col. 1	Millions of £	Per cent of col. 1.
1922–23	151·9	77·1	50·8	74·8	49·2
1923–24	165·0	83·9	50·8	81·1	49·2
1924–25	184·2	91·4	49·6	92·8	50·4
1925–26	205·8	98·9	48·1	106·9	51·9
*1926–27	227·1	104·0	45·8	123·1	54·2
1927–28	256·3	116·1	45·3	140·2	54·7
1928–29	283·4	127·0	44·8	156·4	55·2

* Year of strike.

That the problem of efficient distribution of electricity, as distinct from the production of electricity, calls for examination may be gathered from Table 1, which shows approximately how, in the effort to deliver electricity year by year to the consumer, an increasing proportion of capital is required for distribution as compared with that required for generation.

During the last six years, while capital charges on generation expressed in pence per unit sold have fallen from approximately 0·42d. (1922–23) to 0·34d. (1928–29), the capital charges for distribution have risen from 0·38d. to 0·39d., though the total revenue per unit sold has fallen in the manner shown in Table 2.

A further indication that capital expenditure on distribution is a serious factor in affording progressively cheaper supplies to consumers is the manner in which in the past, notwithstanding greater sales of electricity year by year, the number of units sold per £ of capital tends to decrease rather than to increase (see Table 3).

Although in recent years quite a considerable amount of rural electrification work has been carried out, development has unfortunately been restricted by various factors, including high cost of electrical energy, high cost of transmission in bulk, costly transmission lines and electrical apparatus, lack of well-considered systems of propaganda and of good organization, absence of attractive tariffs, and want of adequate deferred-payment facilities for the provision of electrical wiring installations and apparatus in consumers' premises.

TABLE 2.

Year	Revenue per unit sold	Percentage drop on previous year
1922–23	2·07d.	—
1923–24	1·86d.	10·1
1924–25	1·75d.	5·9
1925–26	1·65d.	5·7
1926–27	1·76d.	—
1927–28	1·55d.	11·9
1928–29	1·44d.	7·1
1929–30	1·38d.	4·2

It is hoped to indicate, from the records and experience of past work in this field, how it may be possible to extend the radius of development and provide a reliable supply for a large proportion of the parishes within the industrial and agricultural counties in Great Britain, and this at a price which will attract custom and yet establish and keep the supply undertaking on a sound financial footing. The future holds out possibilities not only for increased sales for domestic lighting, heating, and power, and for existing industries, but also for the establishment of new industries (leading in all probability to a redistribution of population in healthier surroundings) and for the application of electrical power to the pumping of water or sewage.

TABLE 3.

Year	Millions of units sold	Distribution. Capital expended in millions of £	Units sold per £ of capital
1922–23	3 789	74·8	51
1923–24	4 463	81·1	55
1924–25	5 092	92·8	55
1925–26	5 606	106·9	52
1926–27	5 686	123·1	47
1927–28	7 003	140·2	50
1928–29	7 800	156·4	50

The problem of distribution in rural areas is a variant of the problem in densely-populated urban areas. The country dwellers' desire to obtain supplies of electricity is undoubtedly more marked than that of the town dweller, chiefly because, in the almost total absence of gas, the former has to rely upon wood and coal for heat, and upon candles and paraffin for light. The problem is how to convey electricity to his door at a cost which will prove attractive to him and which will ensure an expanding revenue to the supply undertaker.

The need in Great Britain for special measures for keeping down capital costs is apparent when it is pointed out that the average density of population in rural areas is only 115 persons per square mile as compared with 4 907 for the remainder of the country.

Owing to the need for economy and in face of ruling prices for material and labour, the adoption of standard voltages for transmission purposes and the simplification and standardization of equipment such as overhead lines, transformers, and switchgear, appear to the authors to be inevitable. They envisage the development of rural electrification "on the basis of direct or indirect supplies from the main 132 000-volt 'grid' system of the Central Electricity Board into a secondary system at 33 000 volts, from which bulk supplies will be taken for the 11 000-volt networks of the rural areas, with a final transformation to 400/230 volts for distribution to consumers."*

For rural electrification to be successful the authors are definitely of the opinion that the unit of area must embrace practically all the sources of revenue to be found in the countryside, including villages and one or two small country towns, and most of those "outside" sources referred to later as "isolated consumers." If rural electrification be taken in hand sporadically over small areas, or on the basis of supplies being given to the more lucrative villages and semi-urban districts or to large individual power users chosen because of the immediate prospects of revenue, the problem of a general public supply over wide rural areas, i.e. a supply by which all classes are catered for, becomes much less capable of satisfactory solution.

The area must be large enough to provide a revenue of sufficient magnitude to command the services of good technical and business men and to permit of ample canvassing and publicity services. Consideration must also be given as to what size of area is convenient and appropriate, from the points of view of control and operation and of minimum capital expenditure.

As regards control and inspection during operation, the motor-car and motor-cycle have expanded the radius of well-controlled action at least threefold over that possible by horse and trap. From this point of view an area having a radius of about 10 miles from a central point, i.e. about 20 miles diameter, would appear to offer a workable area. Within such an area a "tertiary" voltage of 11 000 volts, over which a secondary voltage of 33 000 volts is superimposed, presents no serious difficulties in the transmission of energy. From the point of view of capital expenditure it is evident that purchases can be made at lower prices for greater quantities of material, and on the basis of a 2 per cent charge† on revenue to be allocated to active propaganda such an area would appear to represent a minimum size. In the authors' view an area of not less than 400 square miles in extent should be considered for electrification, and multiples of this up to 3 or 4 times might quite conceivably give better results.

(2) GENERAL CONSIDERATION OF DESIGN OF DISTRIBUTION SYSTEMS: AUTHORS' MODEL SCHEME FOR RURAL AREA.

The general design or lay-out must have due regard and give proper weight to the many requirements or conditions to be met, the principal of which may be summarized as follows:—

(*a*) The financial aspects of electricity supply.

(*b*) The requirements of and the limitations set by the principal Statutes relating generally to electricity supply, 1882–1930, and particularly the Act or Order under which the work is to be carried out.

(*c*) The Regulations issued by the Electricity Commissioners relating, among other subjects, to safety of the public, systems of supply, construction of overhead lines, regulation of pressure at consumers' terminals, and other matters (see Electricity Commissioners' publications).

(*d*) The extent and character of the area for which distribution powers are being sought or have been granted; the distribution of the population; the number of parishes (including the number and population of the villages and hamlets within them); the number of isolated residences, institutions, etc.; the number of farms and the extent of the holdings; the nature and extent of the industries either already established or under consideration or possible; and the service, if any, that may be given to other public utilities such as those of water supply and sewage disposal.

(*e*) The demand for electricity and the revenue to be expected in both the earlier and the later stages of development covering, say, a period of 6 years, the estimates prepared in this connection being based as far as possible on an actual canvass, on past experience in other rural areas, etc., and on such statistics as are available.

(*f*) The classes of materials available for use and adaptable to the purpose selected to give a minimum capital expenditure.

The authors do not propose to enter into detail in respect of items (*a*), (*b*), and (*c*), but would merely say in regard to (*a*) that the supply industry continues to afford a sound investment, and, as regards (*b*) and (*c*), the Regulations issued by the Electricity Commissioners offer on the whole no impediment to the selection by the designer of such materials as will admit of types of construction meeting the need for safety and of moderate rates of depreciation, and allowing of low capital costs.

With regard to area, the authors have realized the difficulty of taking for examination a known district as an actual example. Such a course would have led to deductions of a doubtful character, and would have been unlikely to give as true a direction to future development in rural areas as a hypothetical case in which the conditions to be met are assumed to be average conditions as found in this country, with due regard to developments likely to arise within the next few years. The authors have therefore attempted to formulate a scheme embracing average conditions found within the range of likely development and have called it their "Model Scheme."

It will be assumed throughout that the undertaker authorized to give the supply is really desirous of providing a cheap public supply of electricity to all classes in every part of the model area under his control, provided he can be assured of a return sufficient to meet working expenses, interest and depreciation on sums expended, and any early losses, together with a reasonable margin for contingencies.

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* Electricity Commission Bulletin (issued 1930), "Considerations bearing upon the Electrical Development of Rural Areas."

† See Col. Vignoles's Report on visit to America (E.D.A. publication, 1930).

Finally, it will be assumed that the following conditions form the basis of the scheme:—

(*a*) The availability, at a reasonable price, of electricity in bulk at appropriate points in or near the rural area to be developed.

(*b*) Minimum costs of transmission and distribution from the bulk-supply points, by the maximum use of overhead lines for these purposes, the co-operation of the local authorities and land owners concerned in the granting of the necessary facilities, and the adoption of standardized voltages and equipment and a carefully planned lay-out for the area as a whole, the collective aim being the fullest possible economy in capital expenditure consistent with reasonable continuity of supply and safety.

(*c*) The construction of a transmission and distribution system in anticipation of demand, so as to foster rapid development.

(*d*) The adoption of a suitable tariff which will tend to encourage extensions in the use of electricity, once a supply is available.

(*e*) The adoption of a scheme of assisted wiring so that consumers are not faced with the difficulty, in certain cases, of making a large cash payment for connection to the supply system.

(*f*) The establishment of a hire or hire-purchase service whereby electrical cooking and heating apparatus, etc., and electric motors are provided and maintained at a low cost.

(*g*) Active publicity, including a showroom and demonstrations to, and canvassing of, likely consumers.

(3) AREA AND POPULATION OF GREAT BRITAIN: APPLICATION TO MODEL SCHEME.

The total area of Great Britain, after allowing for inland waters, may be assumed to be approximately 88 140 square miles, with a population (1921 Census)* of 42 769 196, i.e. an average density of 485 persons per square mile.

The distribution of the population as between rural and urban areas is shown in Table 4. From this it will be seen that the rural areas comprise upwards of 92 per cent of the total area but only contain 22 per cent of the population, resulting in an average density of 115 persons per square mile. The urban areas, although covering less than 8 per cent of the total and containing 78 per cent of the total population, have an average density of 4 907 persons per square mile.

Of the 81 344 square miles of rural area, arable and permanent grass land account for about 47 610 square miles, and woods, forests, and rough grazing (mountain and heath land), for 30 940 square miles, leaving about 2 794 square miles of "unallocated" land. This is set out in Table 5, which gives the population for England and Wales together, and for Scotland separately.

The densities of population per square mile in rural areas derived from this table are:—

England and Wales ..	151	Great Britain ..	115
Scotland	53		

It has been found impossible from the Census returns to differentiate between the population on land covered by woods and forests, etc. (item 1 in Table 5), and arable and permanent grass land (item 2), but it is estimated from returns of counties in which land of the class covered by item (1) of the table predominates, that a fair figure is about 10 persons per square mile. Omitting such areas and populations, the average density in England and Wales would be about 190 and in Scotland 140.

TABLE 4.

Distribution of Population in Great Britain (based on Census of 1921).

Nature of area	Area		Population		
	Actual	Per cent	Actual	Per cent	Average density per square mile
	sq. miles				
Urban areas	6 796	7·7	33 346 250	78·0	4 907
Rural areas	81 344	92·3	9 422 946	22·0	115
Totals	88 140	100·0	42 769 196	100·0	485

Note.—Urban areas comprise all cities, boroughs, and urban districts, in England and Wales, and all cities and burghs in Scotland. Rural areas comprise all rural districts in England and Wales and all extra-burghal districts, i.e. civil parishes exclusive of burghs in Scotland.

TABLE 5.

Population of Great Britain. Rural Areas Only.

Nature of area	Area		Population	
	England and Wales	Scotland	England and Wales	Scotland
	sq. miles	sq. miles	millions	millions
(1) Woods and forests and rough grazing, mountain and heath land	10 840	20 110	7·851	1·572
(2) Arable land and permanent grass land	40 270	7 340		
(3) Unallocated ..	714	2 070		
Totals	81 344		7·851	1·572

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* The 1931 Census returns have not been used, as the necessary detailed figures are not yet available.

The density-of-population map* shows how the population is distributed over the United Kingdom. Omitting the more sparsely populated areas having densities ranging from 0–60, the remaining portions occupy roughly two-thirds of England and Wales, and one-fifth of Scotland, or approximately 45 000 square miles.

The present position of rural electrification is set out in Table 6, which shows that powers to distribute electricity in rural areas are held over 47 847 square miles, or rather more than the figure of 45 000 given above. The table gives: (1) the total rural areas in England, Wales, and Scotland, separately; (2) areas over which distribution powers are authorized (referred to hereunder as "occupied areas"); (3) (*a*) areas within which electricity has actually been made available by means of low-tension distributing lines; (3) (*b*) areas in which distribution powers have been granted but where no public supply is at present afforded; and (4) districts over which no powers of distribution have as yet been sought. Density of population is given wherever possible. It is interesting to note that those rural parishes in England in which electricity has so far been made available amount to about 7 300 square miles (or 21 per cent of the "occupied" area), with a density of population on the average of 370 persons per square mile, as compared with the remainder of "occupied" area, where supplies are not yet available, of over 26 000 square miles (or nearly 80 per cent) having a density of 126. Similar comparisons are shown for Wales, but the Scottish figures are incomplete. Development has therefore proceeded on the lines of least resistance. Semi-urban areas around cities and boroughs have been tackled first, and the problem as to how, with decreasing density and irregular dispersion, supplies can be given on an economic basis has yet to be solved. It is evident, however, that within those areas having densities round about the average of 126, lie expanses of undeveloped territory offering a field for electrical enterprise.

The analysis of certain returns made to the Electricity Commissioners by 223 authorized undertakers supplying rural areas, goes to show that much of the electrical development which has taken place has been on the basis of specific and, possibly, sporadic extensions of systems, for the express purpose of securing isolated power loads of sufficient value in themselves to justify the initial outlay. In such circumstances transmission lines have been erected to the power user direct, and domestic supply has been regarded as incidental.

The total rural area, i.e. rural districts in England and Wales, is upwards of 51 800 square miles in extent and includes 12 926 parishes, whose average area is 4 square miles.

It may be said that in rural England and Wales villages in the cultivated areas are, on the average, say 2 or 3 miles' walking distance from a man's work, and that market towns are a riding or driving distance of, say, 15 to 20 miles apart.

The rural parish—the smallest division within which self-government is exercised in the country or for which statistics relating to area, population, and premises, are available—usually contains one village as the nucleus.

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* Exhibited as a wall diagram.

TABLE 6.

Rural Electrification.

(Rural Areas comprise all Rural Districts in England and Wales, and all Extra-Burghal Districts, i.e. Civil Parishes exclusive of Burghs, in Scotland.)

	ENGLAND		WALES		SCOTLAND		GREAT BRITAIN	
	Area	Population	Area	Population	Area	Population	Area	Population
	sq. miles		sq. miles		sq. miles		sq. miles	
(1) *Total* Rural area	45 038	7 059 547	6 799	791 735	29 507	1 571 664	81 344	9 422 946
(Density per square mile.)		(157)		(116)		(53)		(115)
(2) Areas over which distribution powers are authorized	34 097	6 090 201	3 855	606 985	9 895	1 057 340	47 847	7 753 726
(Density.)		(178)		(157)		(106)		(162)
(3) (*a*) Area of parishes with distribution powers in which low-tension lines are laid (approximate)*	7 300	2 700 000	700	300 000	not available		—	—
(Density.)		(370)		(429)				
(*b*) Area of parishes with distribution powers but where no low-tension mains are laid (approximate) *	26 797	3 390 201	3 155	306 985	not available		—	—
(Density.)		(126)		(97)				
(4) Areas over which there are *no* powers of distribution	10 940	969 346	2 944	185 550	19 612	514 324	33 496	1 669 220
(Density.)		(88)		(63)		(26)		(49)

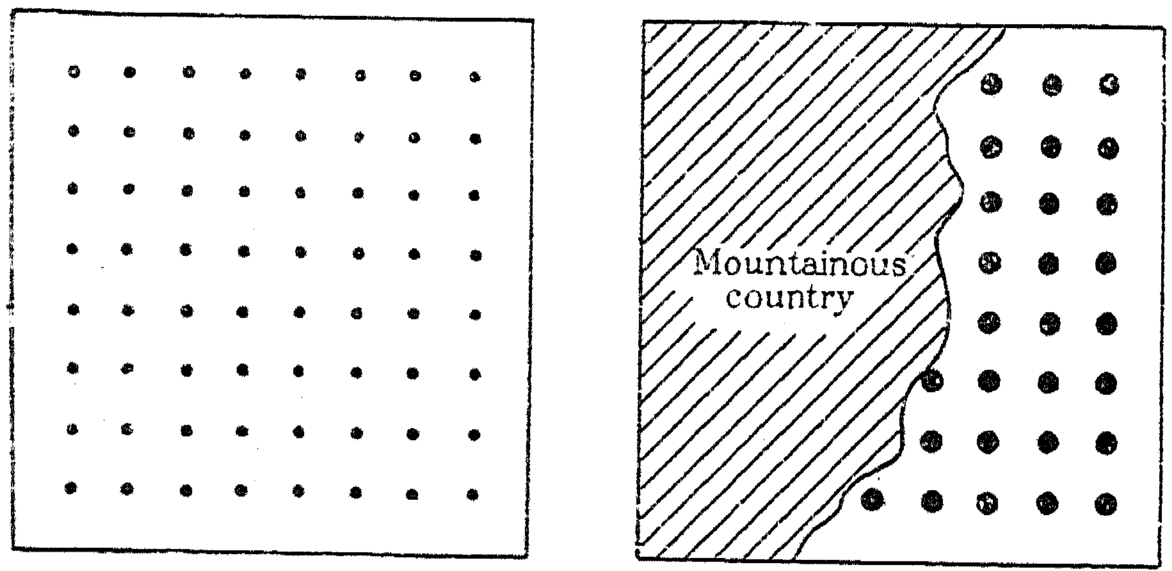
* As estimated to 31st March, 1930. Approximate only.

The parish will be found a useful unit for purposes of design and for statistical reference during periods of progressive electrification.

Villages vary in character and size and reflect the history of the country. In open country and in situations exposed in mediæval times to danger, the dwellings will be found nestling close together for protection. Within near reach of each other are the church, manor house, villas and cottages, and one or two small farms, whereas villages perhaps less exposed to attack and raid may sometimes be distinguished by a straggling, ribbon-like, loosely-knit character. The scale of population in parishes varies considerably, upwards of 16 per cent being composed of communities of under 100 persons; 50 per cent of 100 to 500 persons; and the remaining 34 per cent ranging from 500 to 4 000 or 5 000, the latter being, in fact, small country towns.

The number of farms of 100 acres and over in England and Wales in 1924 was 95 754, situated within the rural area of 51 800 square miles. On the average, therefore, there are about 2 large farms per square mile or 8 per parish. Two or three may be situated close to the village, while the remainder are dotted over the countryside, their diffusion being a gauge of the fertility of the soil.

In Scotland the number of farms of like size is 15 482, giving, if mountain, heath, woods, and forests, are omitted, an average of just over two large farms per square mile. However, sheep farms and a few farms do exist upon the rough grazing lands, and it is probable that a more likely figure for Scotland in cultivated areas is less than 2 farms per square mile.



100 square miles.
Density = 150 per square mile.

100 square miles.
Density = 150 per square mile.

FIG. 1.

Apart from villages and farms, there are country houses, hospitals, colleges, and institutions, which may confidently be looked to as potential consumers of electricity, and finally, scattered at irregular intervals, there are users of power for industrial purposes, ranging from the village smithy equipped with a small 3-h.p. or 4-h.p. motor for blowing the bellows, to large consumers such as brick or cement works and other industries.

Density of population in itself provides an insufficient basis on which to lay out a system of electrical distribution. Two areas equal in size and having the same average density may require different treatment. Take the two areas in Fig. 1. In the first the potential consumers are distributed evenly over the 100 square miles, whereas in the second, taking the shaded portion as mountainous country, the potential consumers are confined to about 50 per cent of the area and are consequently more easily, and perhaps more cheaply, provided with a supply of electricity. Such decided variation in density of population in so small an area would be unusual in normal circumstances, as, normally, density changes more gradually, but it is clear that, if estimated costs of distribution are to be based on density, that estimate which is based on an evenly distributed load will be the highest, and also the safest to adopt.

It has been shown that in England and Wales the density of the population in cities, boroughs, and urban areas, is over 40 times that found in rural districts (see Table 4). So great a difference in density would make electrification practically impossible in competition with coal, paraffin, and wood, if all potential consumers were scattered equidistantly over the countryside. Fortunately, complete diffusion does not exist, most of the population being congregated in villages and hamlets. The remainder is located in country residences, institutions, farms, factories, etc., usually of such a size as to warrant the capital expenditure needed to form an interlinked system of supply for the whole area.

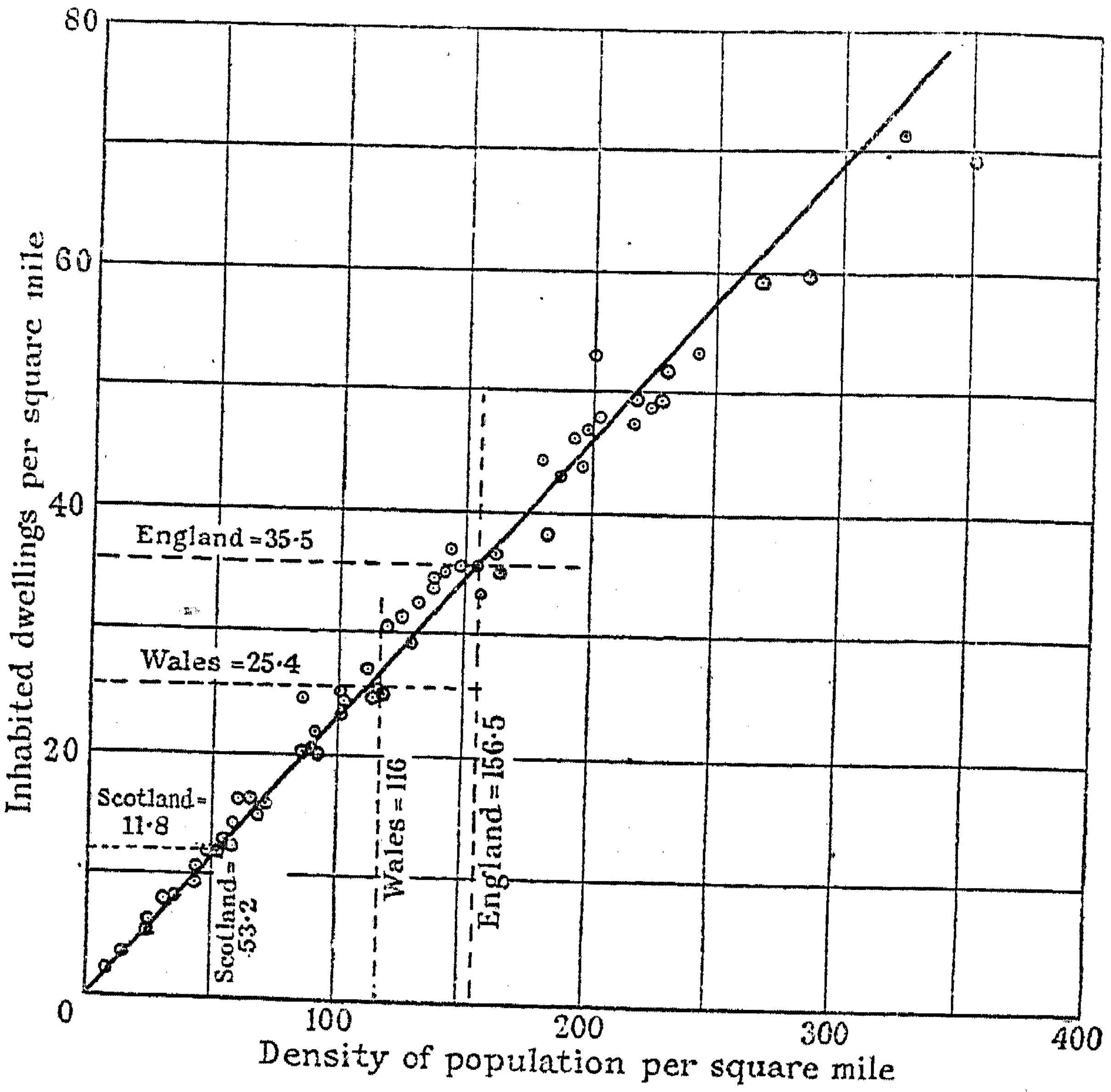


FIG. 2.—Density of population and number of inhabited dwellings per square mile in rural districts (by counties). Figures taken from the 1921 Census tables.

As the relation between population and inhabited houses will be referred to, Fig. 2 is introduced for convenience.

For their Model Scheme the authors have assumed a density of 150 persons and 34 inhabited houses per square mile. They follow this by two schemes of less density, i.e. one based on 100 persons and 23 inhabited houses per square mile, and another based on 75 persons and 17 inhabited houses per square mile.

(4) DEMAND AND REVENUE IN RURAL AREAS.

The extent to which electricity, a highly saleable commodity, is bought is limited principally by the consumer's ability to pay, and by its cost in comparison with that of coal, paraffin, wood, and peat (and in rural areas very occasionally gas), for heating purposes; paraffin for lighting; and petrol, paraffin, heavy oil, water, or steam, for the production of power. A great deal depends on the personality, enthusiasm, and ability of the engineer operating the system; active publicity, salesmanship, and efficient service, have also a marked effect.

TABLE 7.

Demand and Revenue.

	Rural areas only, 1929–30	Whole country, 1928–29
Number of undertakers giving supplies	223	614
Total areas of supply covered, sq. miles	25 689	—
Population in occupied areas (total)	4 841 704	—
Population per square mile in occupied areas	188	—
Premises in occupied areas ..	1 011 870	—
Number of consumers connected:—		
At beginning of year ..	146 687	—
At end of year	203 620	2 994 000
Units sold during year (millions)	507·2	7 800
Revenue from sale of electricity	£2 468 252	£46 993 620
Number of consumers (at end of year):—		
Farms	2 485	—
Domestic	184 738	—
Factories	2 858	—
Other	13 539	—
Total..	203 620	2 994 000
Average revenue per unit sold (pence):—		
Farms	2·29d.	—
Domestic	2·97d.	—
Factories	0·72d.	—
Other	3·50d.	—
Average	1·17d.	1·44d.
Average units sold per consumer *:—		
Farms	1 163	—
Domestic	432	—
Factories	143 425	—
Other	1 075	—
Average	2 491	2 600
Average revenue per consumer *:—		
Farms	£11·1	—
Domestic	£5·3	—
Factories	£434·0	—
Other	£15·7	—
Average	£12·12	£15·7

* Based on number of consumers at end of year.

The facts as to what has so far been accomplished in urban, semi-urban, and rural areas combined, are known from the records available over a period of several years.* As to rural areas alone, an interesting investigation was made in 1930 by the Electricity Commissioners in response to a recommendation of the Conference on Electricity Supply in Rural Areas (9th Annual Report, p. 31). The main facts disclosed are shown in Table 7.

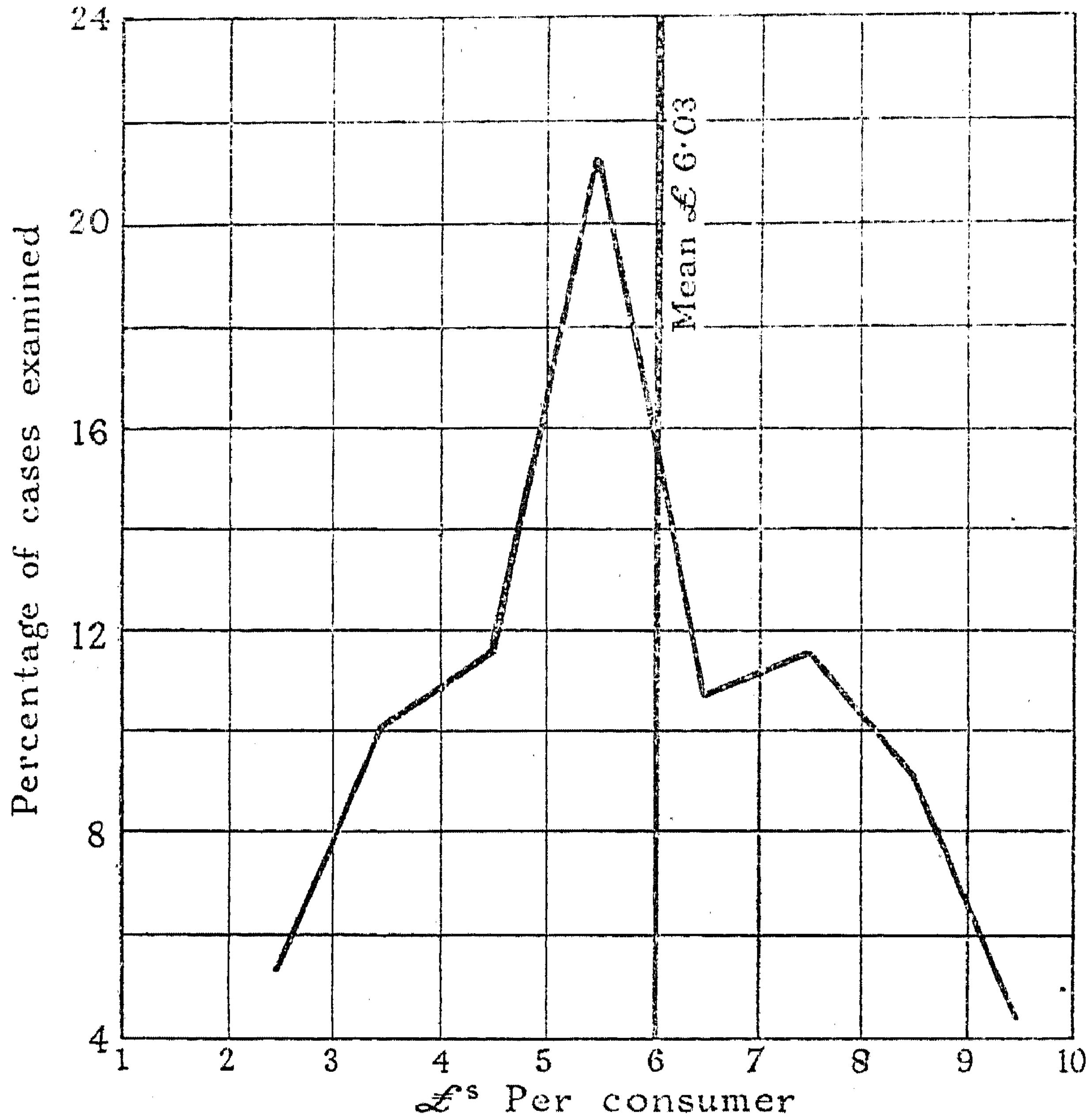


FIG. 3.—Limits of substantial variation in revenue per consumer (excluding consumers taking 15 000 units or more), from rural areas only.

The rural returns have been analysed in a way that focuses attention on the consumer. In the opinion of the authors, revenue per consumer affords the most practical basis on which to build progressive estimates. The consumer may be visualized and his vagaries and idiosyncrasies followed. He is the person to be kept under continuous observation. Revenue based "per head of population" is a less definite conception, except if, and when, related to those people to whom electricity has been made available; moreover, the "per head of population" method of computation presents difficulties, because a parish is the smallest area for which information as to population is available, and supply is frequently only given to part of a parish. Costs, or units "per head of population" of the country as a whole, have, it is admitted, an interest when given periodically, but such figures are of doubtful assistance in marking progress in an expanding undertaking. The authors have consequently adopted the consumer as the basis of all the relative estimates in their Model Scheme.

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* Electricity Commissioners' Statistical Returns, 1922–29.

One of the most striking facts brought to light by recent official statistics (1928–29) is that the average revenue per consumer amounts to £15·7 for the whole of Great Britain, and to £12·12 for rural areas alone, the figures being based in each case on the number of consumers at the end of the year. It is interesting to note how a consumer, once obtained, has become, under the cultivation extended to him in the past, such a potent source of revenue.

If, in the case of the country as a whole on the one hand, we omit units sold and revenue obtained from power users, tramways, and railways, i.e. about 67 per cent of the total units sold; and, on the other hand, in the case of rural areas, all consumers of 15 000 units and over—representing, practically, the units derived from factories and collieries (railways and tramways not being operated from rural centres), or about 88 per cent of the total—the remaining revenues per consumer become approximately £8 (whole country) and £6 (rural), respectively. As to the revenue received from domestic users only, information as regards the whole country is not available, but the average obtained from the rural returns is £5·1 (see Table 7).

It is interesting to observe, from Fig. 3, the limits of substantial variations in revenue from consumers other than those using 15 000 units and over per annum in rural areas. The diagram indicates that around a mean of £6·03 revenue per consumer the variation ranges between £2 10s. and £9 10s., and this embraces 95–96 per cent of the whole of the cases examined. It is difficult to say whether the low-revenue results are due to too high a tariff, lack of attention to domestic users, want of assisted wiring and apparatus on easy terms, or to early stages of development. It seems reasonable, however, to think that if no new customers were to be connected the mean of £6·03 would move further towards the £9 10s. limit, provided an attractive tariff of charges were offered.

TABLE 8.

Size of rural area (square miles)	Excluding large consumers of 15 000 units and over		
	Units sold per consumer (average)	Revenue per consumer (average)	Price per unit (average)
0–25 (nearest urban centres)	437	£6·20	3·41d.
25 and under 100 ..	562	£6·73	2·88d.
100 and under 250 ..	409	£5·70	3·35d.
250 and over ..	423	£5·43	3·08d.

The proximity of the consumer to centres of population does not appear to have any marked effect on the results, as the figures given in Table 8 show.

The object therefore must always be to find new customers, with the knowledge that once connected, and well served with tariffs graded to expanding use, careful use of capital, efficient service, assisted wiring, and wise selection of apparatus, the consumers will provide increasing revenue as time goes on.

TABLE 9.

Demand and Revenue. Expenditure for Lighting, Heating, and Cooking.

FROM A SUSSEX VILLAGE.*

Class of property	Expenditure per week (winter months)
Small cottages	4s. to 5s. 8d.
Larger cottages and villas ..	6s. to 8s. 1d.
Public houses	8s. 1d. to 9s. 6d.
Shops	8s. 1d. to 10s. 6d.
Garages and repair shops ..	5s. 8d. to 8s. 1d.
Laundry	28s. 8d. to 30s.
Village hall	5s. 7d.
Village chapel	5s. 7d.
Railway station	42s. 6d. to 46s.

* These figures and those below have been supplied by courtesy of Miss C. Haslett, C.B.E., Director, The Women's Electrical Association.

FROM WORCESTERSHIRE.†

Class of property	Expenditure				
	Per week		Per annum		
	s.	d.	£	s.	d.
Small cottages (W.S.) ..	0	10	2	3	4
Small cottages (W.N.) ..	1	1	2	16	4
Larger cottages and villas (W.S.)	1	3	3	5	0
Larger cottages and villas (W.N.)	1	4	3	9	4
Larger residences (W.S.) ..	15	6	39	0	0
Village farms (W.S.)	7	7	19	14	8
Larger farms (W.S.)	14	9½	38	10	0
Churches (W.S.)	3	8	9	10	0
Churches (W.N.)	4	10	12	12	0

† W.S. = Villages in Worcestershire, South.
W.N. = Villages in Worcestershire, North.

The consumer's ability to pay is an important factor when considering the possibilities of ultimate revenue. On the whole, for domestic purposes rural dwellers might be thought to be unable to expend as high a sum per annum for light and heat as their neighbours in the city and urban centres, simply because their incomes are smaller. On the other hand, gas competition is practically absent and competitors in public service are reduced to coal, paraffin, and wood, and in some cases peat. It should be remembered that the allocation of the weekly or monthly expenditure is different in the case of the country dweller from that of the town dweller. Home life remains more attractive and more the centre of remunerative expenditure in the country. It is not, however, always realized that these means of providing home comfort, cooking, and heating, cost in themselves quite a large sum relative to the income, and as an example the figures in Table 9 showing actual expenditures by village dwellers at present in Sussex and

Worcestershire are of interest. Table 10 is given as a fair endeavour to present as true an average as can be gathered. Different classes of consumers are given, coupled with expectation of revenue (principally from lighting for the first year or two), and the ultimate revenue that might be expected from complete electrification, could electricity be delivered so as to give equivalent comfort and ease at the same cost and with the same degree of security. These figures are supported from inquiries made in several parts of the country and summarized in Table 8.

TABLE 10.

Saturation Revenue = Revenue based on use of Paraffin for Light, and of Coal, Wood, and Paraffin, for Cooking and Heating.

N.B.—No expenditure for power is included, except in the case of farms and large residences.

	Revenue at commencement			Saturation revenue (based on light from paraffin and heat from fuel)		
	Per annum	Per week		Per annum	Per week	
	(a) (b)	(a)	(b)	(a) (b)	(a)	(b)
		s. d.	s. d.		s. d.	s. d
Small cottages (3–4 rooms)	£2·5 to £3·5	0 11½	1 4	£8 to £10	3 1	3 10
Large cottages (4 rooms)	£3·5 to £4·0	1 4	1 6½	£10 to £15	3 10	5 9
Council houses (4 rooms)	£3·5 to £4·5	1 4	1 9	£15 to £20	5 9	7 8*
Small villas (6 rooms)	£4·0 to £5·0	1 6½	1 11	£18 to £22	7 0	8 6
Large villas (6 rooms)	£5·0 to £7·0	1 11	2 8	£20 to £25	7 8	9 6
Shops and rooms	£5·0 to £6·0	1 11	2 4½	£15 to £20	5 9	7 8
Small inns	£6·0 to £8·0	2 4½	3 1	£15 to £20	5 9	7 8
Public houses	£8·0 to £10·0	3 1	3 10	£25 to £30	9 6	11 6
Churches and chapels	£5·0 to £6·0	1 11	2 4½	£8 to £9	3 8	3 6
Schools	£3·0 to £4·0	1 2	1 6½	£10 to £15	3 10	5 9
Farms (village)	£5·0 to £8·0	1 11	3 1	£12 to £15	4 7	5 9
Public lighting	£2·0 to £3·0	0 9	1 2	—	—	—
Large farms	£6·0 to £8·0	2 4½	3 0	£20 to £25	7 8	9 6
Large residences	£20·0 to £30·0	7 8	11 6	£50 to £100	19 3	38 6

* In certain urban council houses in Manchester occupied by 5 persons, the "saturation" revenue is anticipated (electricity and coal) to be £20 0s. 11d. or 7s. 9d. per week at 0·9d. per unit.

That the capacity to purchase may be high will be gathered from Table 11, which shows the units sold and total revenue for lighting and for heating, cooking, and small domestic apparatus, separately, as actually noted from the accounts of three classes of consumers in the rural district close to Bedford. From these indications and from evidence accumulating on many sides, it is evident that the scope for the sale of electricity in rural areas is much greater than is generally realized, and that in designing distribution systems for electricity supply an expansion of a high order should be anticipated and, as far as possible, allowed for in the general framework of the design.

A further indication of the possibilities of domestic demand may be gained from Table 12, which shows the actual expenditure incurred for electricity and fuel separately and together, over a period of a year in six households.

The ultimate revenue to be derived from farms is difficult to estimate. The extent of the demand at present—as disclosed by the Electricity Commissioners' Rural Returns 1929–30—is shown in Table 13.

The "saturation" revenue from the farmhouse might possibly be gauged and the extent to which power could be applied electrically to the processes found to be needed within the farm-buildings might be assessed, but it appears at the moment impossible to measure even roughly the limit of its application to the heavier duties of ploughing and tilling, mowing, and reaping. Experiments are now being made, but for the moment the horse and the petrol or paraffin engine seem literally to hold the field. For a farm with an average of 80 acres under cultivation the authors would therefore be disinclined to assume a higher annual return than £25, even at saturation point and including power.

Revenue from Power Users.—That the revenue to be derived from the various sources other than domestic is most material to the successful issue of any rural electrification scheme, is evident. The returns already mentioned show that within the 9 000 or 10 000 square miles of comparatively rich rural area at present electrified to some extent in Great Britain, a revenue of about £1 246 000 has been derived from 1 042 consumers, as shown in Table 14.

The revenue per consumer is on the average about £1 196, and units sold are 396 120. Power consumers are about 0·5 per cent of the total consumers, and power units far exceed those sold for other purposes, being upwards of 80 per cent of the whole. This compares

TABLE 11.

Individual Connections in a Rural Area, in which Bedford Corporation has been supplying for 2–3 Years, lying within 2 miles of the Borough.

Description of dwellings	Lighting			Heating, cooking, etc.			Total revenue	Remarks
	Units sold	Rate	Revenue	Units sold	Rate	Revenue		
			£ s. d.			£ s. d.	£ s. d.	
(1) Cottage (3 to 4 rooms)	79	8d.	2 12 8	1 686	1¼d.	8 15 7½	11 8 3½	Lighting and cooking only
(2) Cottage (3 to 4 rooms)	63	8d.	2 2 0	1 200	1¼d.	6 5 0	8 7 0	Cooking only
(3) Cottage (3 to 4 rooms)	71	8d.	2 7 4	1 273	1¼d.	6 12 7	8 19 11	Cooking only
(4) Farm (8 rooms)	227	8d.	7 11 4	630	1¼d.	3 5 7½	10 16 11½	Heating only
(5) Farm (10 to 11 rooms)	362	8d.	12 1 4	3 027	1¼d.	15 15 4	27 16 8	Cooking and heating
(6) Villa (8 rooms)	445	8d.	15 8 4	2 275	1¼d.	11 17 0	27 5 4	Heating only
(7) Villa (10 rooms)*	587	8d.	19 11 4	6 813	1¼d.	35 9 9	55 1 1	Cooking and heating, electric sweeper, wash boiler, electric iron
(8) Villa (6 rooms)	123	8d.	4 2 0	2 081	1¼d.	10 16 9	14 18 9	Cooking and heating
(9) Villa (12 rooms)	225	8d.	7 10 0	2 720	1¼d.	14 3 4	21 13 4	Cooking and heating, electric iron
Total	2 182	8d.	73 6 4	21 705	1¼d.	113 1 0	186 7 4	

* This is above the average consumption.

with 72 per cent (1928–29) for units sold for power and traction purposes by the whole of the authorized undertakers in the country.

The authors would feel some hesitation in basing future prospects in rural areas on such figures, but, as pointed out by those in intimate contact with rural extensions, there is scope for wide developments.

It has been said* that " Contrary to a quite prevalent idea, industrial enterprises are not confined to town and urban areas; in fact, in carrying out electrical development in rural districts an interesting feature has been this discovery of load from industries, the existence of which had been but very little appreciated previously. The advent of electricity supplies to these enterprises in rural parts, together with the great advances made in transport, has undoubtedly checked what was a tendency some years ago for such industries to gravitate into the industrial centres. Further, it is found that new industrial enterprises are now being established in rural localities where, no doubt, some time ago the sites would not have been considered at all suitable." Apart from the possibilities thus indicated, it is difficult to find reasons why in the public services such as those of village and district water supply, sewage disposal, and electricity supply, co-operative action should not now be taken. As an example, water might under certain circumstances be pumped from artesian wells locally and a network of light pipes carrying " make-up " might be laid in the place of larger pipes carrying full supplies greater distances from some central sources. Electricity in such developments could offer some assistance. For drainage purposes in low-lying ground and fen-land, electricity would be a boon and could be made available at off-peak periods at a cost which would offer favourable comparison with other methods of drainage. For their Model Scheme the authors have been careful not to

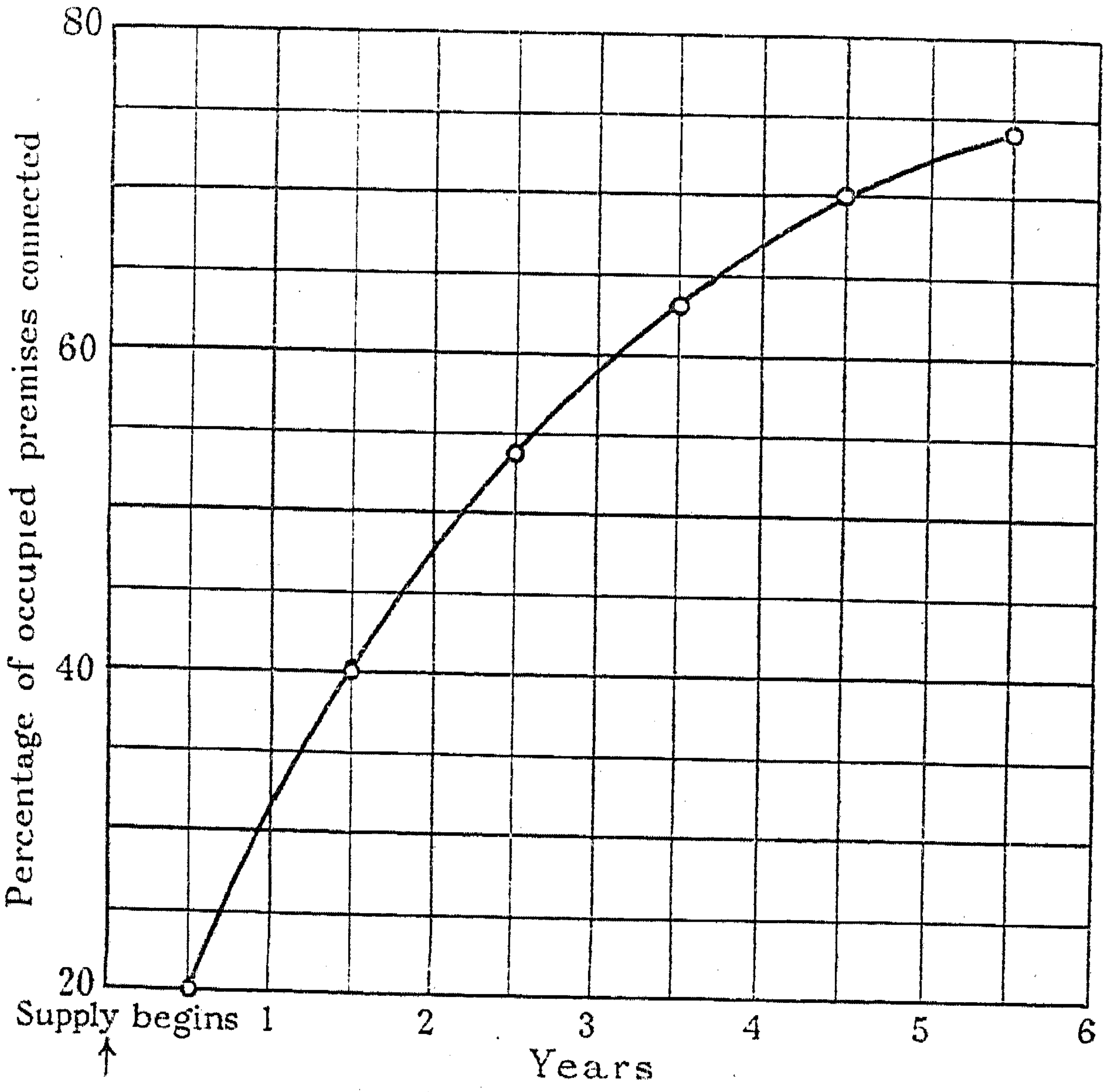

FIG. 4.—Estimate of growth of connections in localities in which electricity is made available.

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* J. T. H. LEGGE: *Electrical Review*, 1930, vol. 107, p. 625.

anticipate too high a figure for power units sold, and have concluded that a safe figure of 33⅓ per cent of the total units sold for the first year and 43 per cent for the sixth year can be taken with confidence.

TABLE 12.

*Analysis of Figures of Cost for Electricity and Coal in Six Households.**

Number	Number of persons in occupation	Number of days in occupation	Approximate volume of house	Units consumed	Total cost of electricity			Cost of fuel			Total cost		
			cub. ft.		£	s.	d.	£	s.	d.	£	s.	d.
1	3	366	7 422	6 675	15	12	9		—		15	12	9
2	2	365	9 990	7 375	17	18	2		—		17	18	2
3	4	337	7 065	7 292	16	17	10	2	0	0	18	17	10
4	3	344	12 500	7 310	17	12	7	7	0	0	24	12	7
5	5·5	350	13 540	6 671	19	6	8	9	7	0	28	13	8
6	5·5	350	20 500	10 540	29	0	0	10	0	0	39	0	0
Total	23	2 112	71 017	45 863	116	8	0	28	7	0	144	15	0
Average ..	3·9	352	11 836	7 644	19	8	0	4	14	6	24	2	6

* Abstracted from *Electrical Age*, April 1930, p. 628.

TABLE 13.

Classification	Actual revenue (approx.)
Class A. Farms in areas 0–25 sq. miles ..	£10·4
Class B. Farms in areas 25–100 sq. miles .	£10·0
Class C. Farms in areas 100–250 sq. miles	£10·9
Class D. Farms in areas 250 sq. miles and over	£12·8
Average (all classes)	£11·1

To give an indication of the number of inhabited houses it is possible on the average to connect to the supply mains in the course of development, Fig. 4 is shown. This has found general acceptance as a fair view of the possibilities of obtaining custom under the conditions of service and publicity allowed for. In various districts where gas is not available, it has not been a rare experience to find in some villages that 95 per cent of the inhabited dwellings are connected within the first 12 months. On the other hand, great difficulty has been experienced in some parts in obtaining applications from more than 10 per cent to 15 per cent of the occupiers within that period, again indicating the need for spreading the net widely. The offer of assisted wiring on all schemes of development has a marked effect in obtaining custom, as so frequently the refusals are due not so much to unwillingness to take a supply—everyone with war experience and by reasons of better transport facilities is nowadays electrically minded—as a lack of the £5 or £6 of ready money to pay for the installation. The authors would urge the necessity, under assisted wiring schemes, of the undertaker providing one power plug for every two lights, in intelligent anticipation of developments shortly to occur under adequate "service." They are not sure whether, in new areas about to be developed, it would not be wise to consider the possibilities of free wiring, charging capital account with the expenditure. The methods by which the undertaker might otherwise recoup himself are many and are dealt with in a recent report issued by the Electricity Commissioners.†

On the whole, therefore, reviewing the ascertained, probable, and possible sources of revenue in rural areas, it is evident that expansion of a high order should be anticipated and allowed for in the general framework of the design.

TABLE 14.

Revenue from Power Consumers using 15 000 *units and upwards in Rural Areas* (1929–30).

Class of area	Number of consumers	Units sold	Revenue, total	Revenue per unit sold
sq. miles		millions		
0–25	86	17·76	£72 742	0·983d.
25–100 ..	244	88·30	£254 887	0·692d.
100–250 ..	98	66·79	£180 802	0·650d.
250 and over ..	614	239·91	£738 141	0·738d.
Totals ..	1 042	412·76	£1 246 572	0·725d.

The authors consider that, provided all known means are taken to cultivate custom, a fair and moderate revenue to be anticipated from consumers within widespread rural areas is on the average that shown in Table 15—and these figures have been introduced into the Model Scheme.

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† Electricity Commissioners' Report on Assisted Wiring and the Hiring, etc., of Electrical Apparatus, 1930.

TABLE 15.

Average Revenue per Consumer (previously connected or connected during Current Year).

	Number of years connected (see loading table, Model Scheme)					
	1	2	3	4	5	6
All classes of consumers	£5·31	£6·54	£7·44	£8·29	£9·19	£10·06

These figures are to be compared with an average of:—

£15·7 actually obtained from consumers connected to the mains of authorized undertakers in Great Britain (1928–29), and
£12·0 from consumers in rural areas only (1928–29).

The detailed figures given in Tables 16A and 16B are supported from returns for the year ended 31st March, 1931, received from the Bedford Demonstration Scheme, where the revenue from the average domestic consumer is £5·93 after a period of availability of supply averaging 2½ years, and with the application of a tariff higher than that scheduled in the Model Scheme.

TABLE 16A.

Year	Number of consumers			Total units sold			Total revenue		
	Total	A	B	Total	A	B	Total	A	B
				thousands			£	£	£
1	2 610	2 600	10	783	520 000	263 000	13 847	13 000	847
2	5 220	5 195	25	3 081	1 870 200	1 210 800	34 150	30 380	3 770
3	7 050	7 015	35	6 204	3 647 800	2 556 200	52 470	44 530	7 940
4	8 225	8 185	40	9 623	5 565 800	4 057 200	68 170	55 665	12 505
5	9 140	9 095	45	13 342	7 639 800	5 702 200	83 960	66 525	17 435
6	9 530	9 480	50	16 678	9 480 000	7 198 000	95 900	73 870	22 030

A = Domestic, public, and small power. B = Large consumers.

TABLE 16B.

Year	Units per consumer			Price per unit			Revenue per consumer		
	Total	A	B	Total	A	B	Total	A	B
				d.	d.	d.	£	£	£
1	300	200	26 300	4·24	6·00	0·773	5·31	5·00	84·7
2	590	360	48 430	2·66	3·90	0·747	6·54	5·85	150·8
3	880	520	73 060	2·03	2·93	0·745	7·44	6·35	226·9
4	1 170	680	101 430	1·70	2·40	0·740	8·29	6·80	312·6
5	1 460	840	126 715	1·51	2·09	0·734	9·19	7·31	387·4
6	1 750	1 000	143 960	1·38	1·87	0·738	10·06	7·80	440·6

A = Domestic, public, and small power. B = Large consumers.

(5) DIAGRAMMATIC LAY-OUT OF THE MODEL SCHEME IN RELATION TO THE GRID.

It is desirable that some conception of the general relation of the grid to the network required for rural areas should be visualized, and therefore Fig. 5 is given to make as clear as possible the view which the authors are taking.

The area shown (160 × 160 miles = 25 600 square miles, or about half the rural area of Great Britain) is divided into sections of 400 square miles each. The heavy black lines represent diagrammatically the 3-phase 50-cycle 132 000-volt grid of the Central Board, interconnecting industrial areas disposed around centres of industry marked A, B, C, and D; and secondly, large and small towns marked by a rectangle, some of which may be selected stations and some provided with supplies from the grid.

The dotted lines indicate the Central Board's 33 000-volt secondary system, or, alternatively, part of a power company's transmission system conveying supplies in bulk at this pressure to 4 points (in this case) within areas of 100 square miles each, and at these points being transformed to a pressure of 11 000 volts to form a tertiary system for final transformation to the consumer's voltage of 400/230.

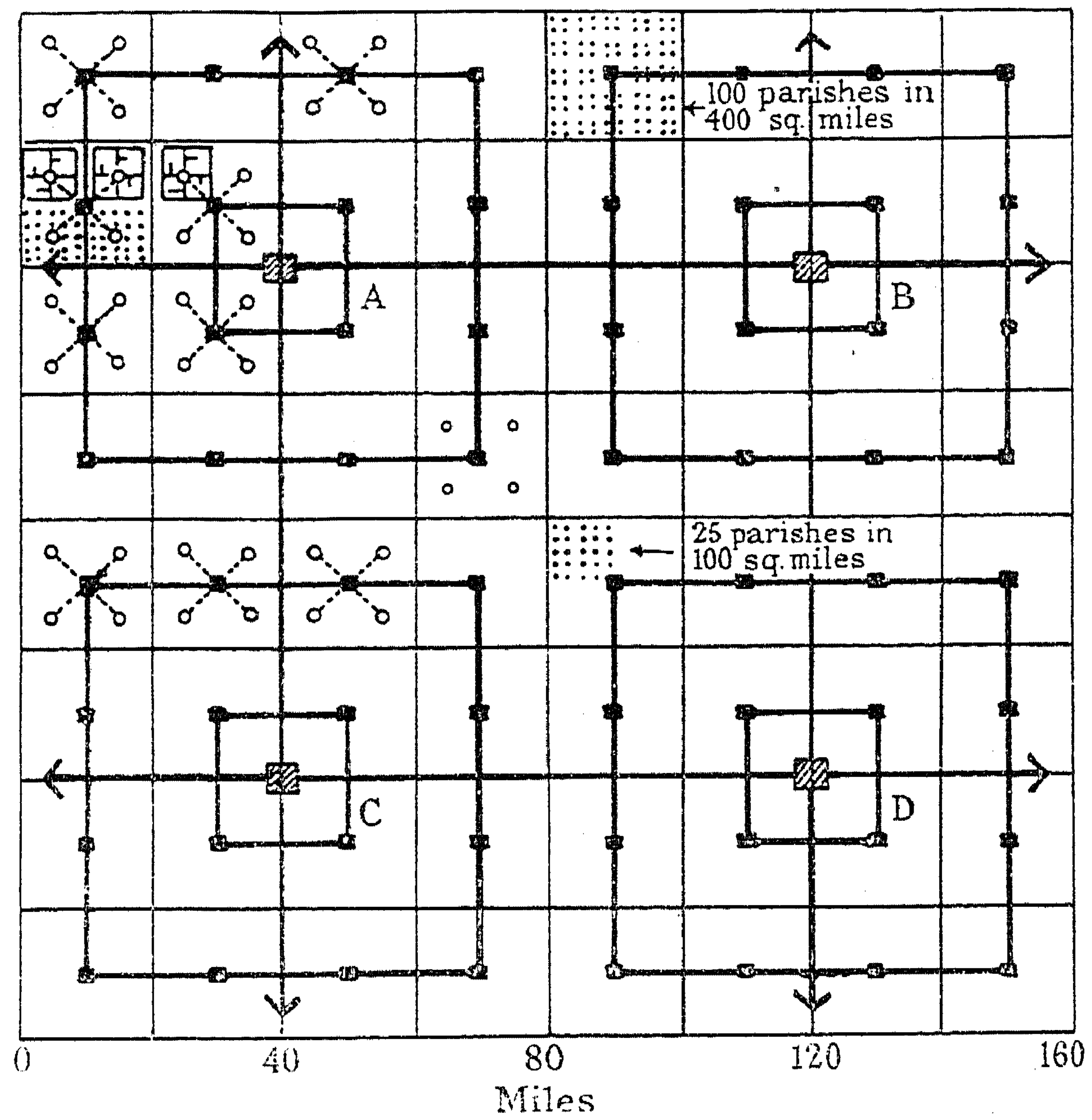

Fig. 5.—Diagrammatic lay-out of the Central Electricity Board's transmission system, showing relation to 11 000-volt rural electrification systems. Total area = 25 600 square miles.

▨ = Industrial areas and centres of large population.

■ = Large towns. Grid-points.

○ = Smaller towns. Points of supply to urban districts and/or centres for rural distribution.

——— = 132 000-volt transmission lines (Central Electricity Board).

------ = 33 000-volt transmission lines (Central Electricity Board or authorized undertaker).

⊞ = 11 000-volt transmission lines (authorized undertaker).

(6) Cost of Bulk Supplies to Rural Areas.

Reference has been made to the advent of the Central Electricity Board into the arena of electricity production and transmission. It is an event of singular importance to the expansion of electricity supply in rural areas. With the co-operation of the Board it may be, and is likely to be, found possible to provide for additional points of bulk supply if needed for extended rural areas. Where the centre of the rural area to be electrified on an economically arranged lay-out coincides with a known grid point, or where supplies in bulk from a power company deriving initially its supplies from the Board's system can be brought to a convenient spot under the terms of the Electricity (Supply) Act, 1926, nothing should, with good will, arise to prevent terms being arranged, having as a result a low cost of bulk supply for rural electrification.

In a few years' time the Board will be supplying all authorized undertakers either directly or indirectly, and, until costs of production are available and the Board have announced their grid prices, it is impossible to give any close figures. For the purpose of this paper it has, however, been assumed that undertakers may receive a supply at an average price of £3 5s. per kilowatt and 0·20d. per unit, at power factors ranging from 0·85 to 0·9. Fig. 6 shows the effect of load factor on such charges in terms of unit cost, and it will be noted that the price for bulk supplies would be approximately 0·64d. per unit at 20 per cent load factor, and about 0·56d. at 25 per cent load factor.

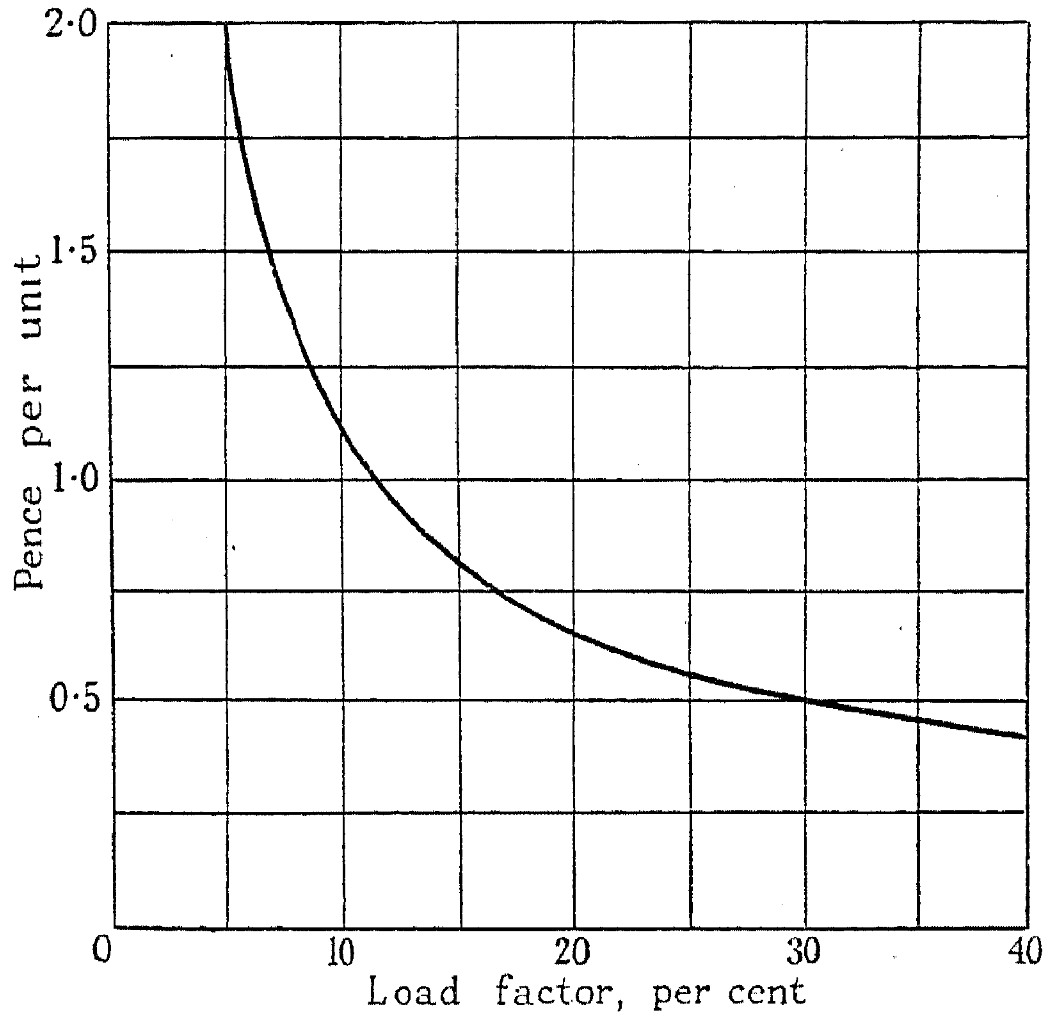

Fig. 6.—Cost of supplies of electricity in bulk.
Curve based on tariff of £3·25 per kW + 0·2d. per unit.

(7) Load Factor at Point of Bulk Supply, and Losses in a Rural Area.

Little reliable data are available on which to base estimates of load factor and losses in a rural system of the character under consideration, as most of the rural supply systems of any size and age are interconnected with the related urban distribution networks. Any close determination of these items is therefore rendered somewhat difficult. By the courtesy of local engineers the authors are enabled to give curves (see Fig. 7) embodying the considered opinions thus obtained.

As to load factors there are, of course, differences in the mode of life between the town and country dwellers. In one undertaking where most of the electricity sold for rural work is for domestic purposes, the peak occurs on a Sunday morning. In others where most of the electricity is being used for power purposes, load factors as high as 30 or 40 per cent have been obtained. If the domestic cooking and water-heating load is cultivated and a fair proportion of power units are sold, there seems no reason why load factors for rural areas should not rise to an average equalling that of the general supply in the country, viz. about 30 per cent. The authors prefer to be cautious and have adopted the curve shown, indicating a rise from 10 to 15 per cent during the first year, to 23 per cent by the end of the sixth year, and to 25 per cent by the tenth year.

The information as to losses between the units bought for transmission over the 11 000-volt system and the units sold to consumers is somewhat more definite and is roughly calculable. The authors' considered opinion is that in view of transformer losses—which are relatively high in such systems—a loss of not less than 20 to 25 per cent on the units purchased should, on the average, be taken in the earlier years of development.

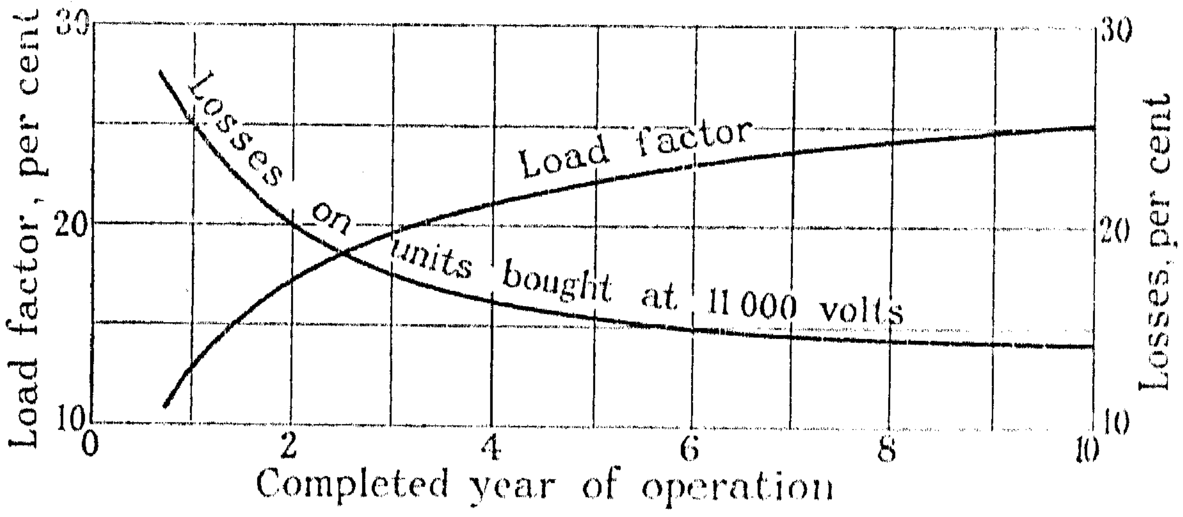

FIG. 7.—Curve showing increase in load factor during development.

The curve indicates a fall from this figure to what is considered to be a reasonable normal figure of 14 to 15 per cent after a number of years of development.

(8) COST OF ELECTRICITY TO THE CONSUMER: TARIFFS.

Cost of Electricity to the Consumer.

The amount of electricity taken by the consumer has a definite relationship to the price charged. If the price is high the consumption is likely to be low because the consumer can satisfy his requirements for light, heat, and power, more cheaply by some alternative means.

The manner, therefore, in which the quantity of electricity used fluctuates with the varying prices charged, calls for investigation.

In order to ascertain the facts, an examination was made of the returns of 221 authorized undertakers operating within rural areas in Great Britain, with a view to determining more precisely what relationship, if any, existed between (i) the units sold per consumer, and (ii) the revenue received in pence per unit sold.

As will be noted from the plotted determinations shown by "dots" in Fig. 9, some relationship does exist. The "dots" form themselves into a curve having a fairly well-defined trend, of which the shape can be observed, and which appear to follow a hyperbolic law.

The determinations of price per unit and units sold per consumer were arrived at from the following particulars:—(*a*) Total units sold; (*b*) total revenue received; and (*c*) the number of consumers at the end of the year of account taken from each return, being the results of operation within rural areas only during the period 1929–30.

The returns were then set down, *seriatim*, in order of units sold per consumer. The average was struck for the whole series, and subsequently these series were divided into two equal portions. Similar investigations were then made upon the returns of each portion.

The results of the three investigations are:—

(1) Mean of portion containing the series of smaller consumers:—343 units at 4·0214d. per unit.

(2) Mean of whole series:—2 481 units at 1·1894d. per unit.

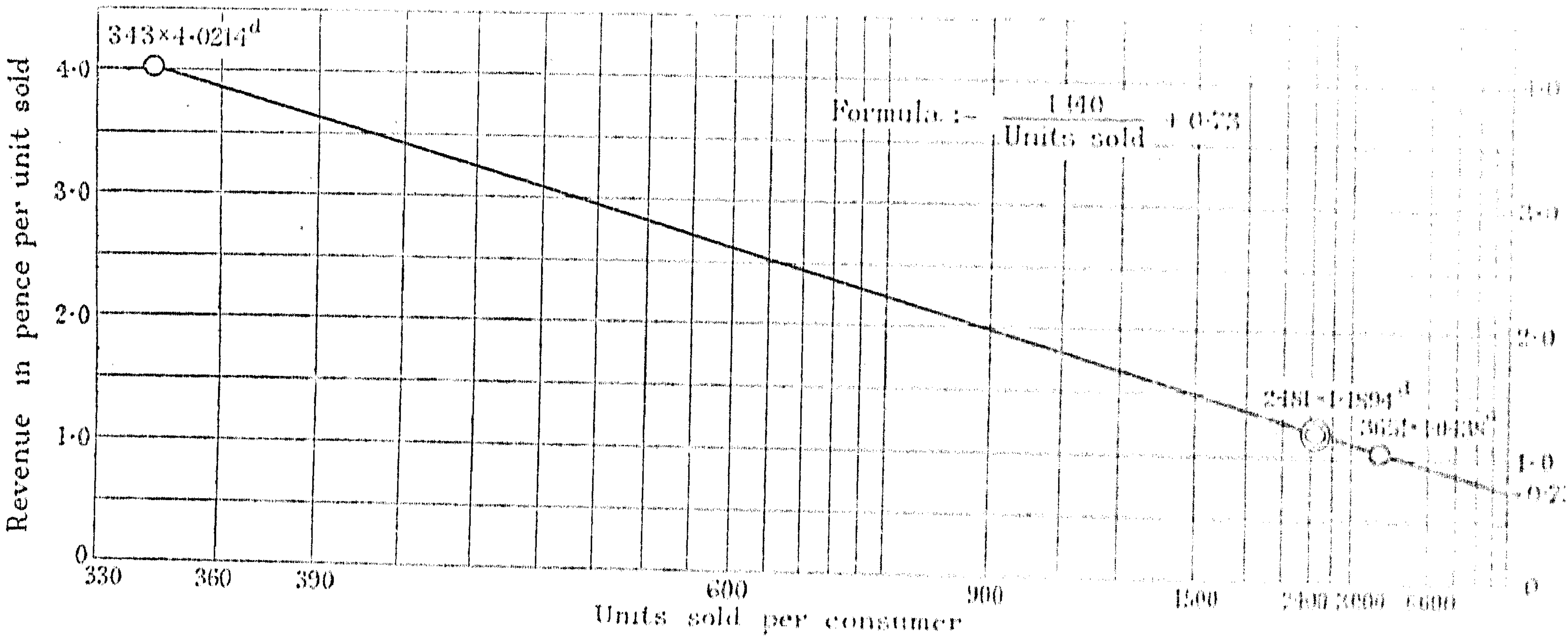

FIG. 8.—Method of determining form of curve AB shown in FIG. 9.

(3) Mean of portion containing the series of larger consumers:—3 651 units at 1·0438d. per unit.

These three determinations were set out on hyperbolic costing paper (see Fig. 8) and the "infinity unit cost" (i.e. the unit cost stripped of all fixed charges) was found to be approximately 0·73d. per unit, giving the appropriate formula

$$\text{Cost per unit (pence)} = \frac{1\,140}{\text{Units sold per consumer}} + 0 \cdot 73$$

The curve derived from this formula is shown in Fig. 9 by the line AB, and, as will be seen, it appears to follow closely the mean of the plotted determinations.

Line CE, the product of the number of units sold per consumer at the price shown on curve AB, gives the total revenue in £'s per annum from consumers of varying demand. The line CE, it will be observed, strikes (like a " Willans " curve) the left ordinate at a point representing £4·75 of revenue per annum (as shown on the right-hand ordinate scale). On the average, therefore, if all kinds of consumers were treated alike in respect of a " fixed " and " unit " charge, they would be called upon to pay £4·75 plus 0·73d. per unit consumed. Such an arrangement of charge is, in actual practice, obviously impossible, and some readjustment of the fixed charge and consequently of the unit charge will have to be considered. This question is dealt with under the subsection " Tariffs " below.

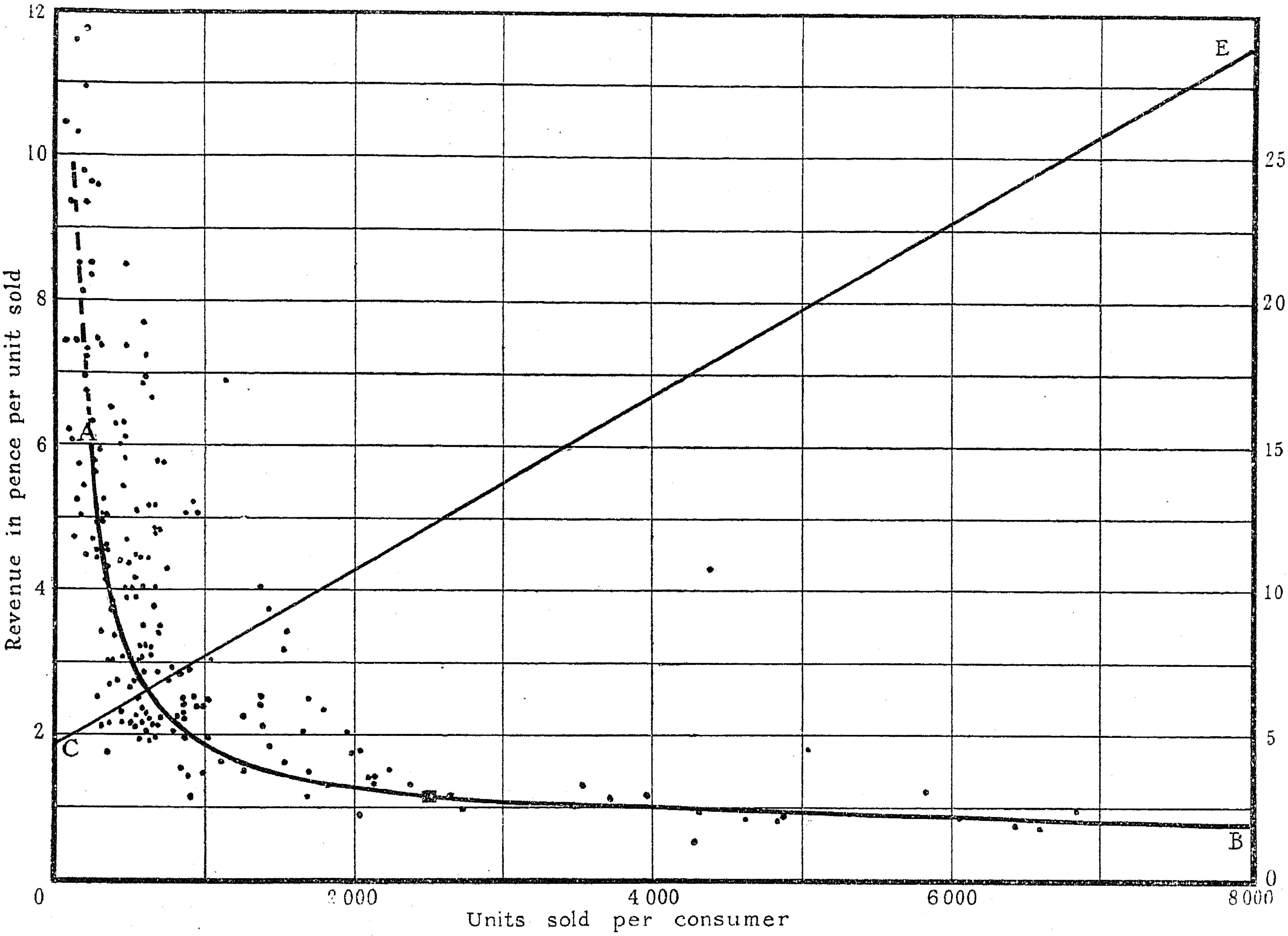

FIG. 9.—Results of operation of 221 authorized undertakers (rural supplies), 1929–30.

TABLE 17.

10 per cent drop in the average charge		Average receipts per consumer		Increase in revenue
From	To	From	To	
d.	d.	£	£	per cent
10	9	5·10	5·15	0·98
8	7·2	5·20	5·29	1·73
5	4·5	5·45	5·60	2·75
2·5	2·25	6·60	6·90	4·55
2	1·8	7·30	7·70	5·48
1·5	1·35	8·80	9·85	12·35

Several interesting points arise from a study of Fig. 9, the more striking being:—

(1) *That any drop in the charge per unit to consumers results in an increase of revenue.*—The extent of the increase in revenue appears to depend on the point taken on the curve when making the comparisons. Assuming a 10 per cent drop in the charge, the effect at varying points on the curve may be observed from an examination of the figures given in Table 17.

The small percentage increase in revenue, observed in the higher rates of charge, seems to account for the nervousness felt by certain undertakings having high tariffs to lower their charges to the consumer. The remarkable gains on the lower series of charges should be noted.

(2) *That any increase in the quantity used should entitle the consumer to expect a lower charge per unit.*—This is indicated by the figures in Table 18.

(3) *The exceedingly wide variations from the mean in the*

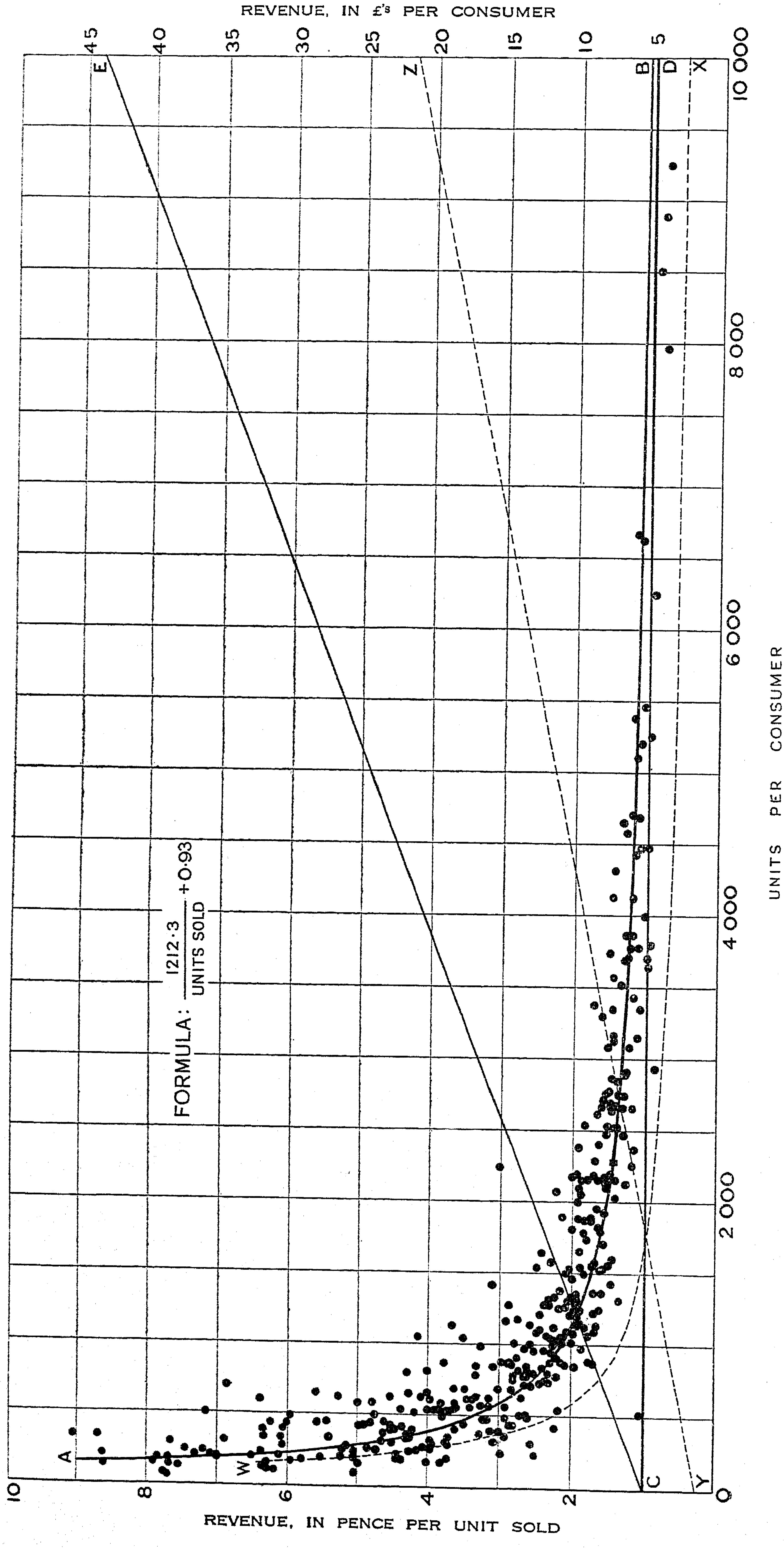

Fig. 10.—Results of operation of 355 authorized undertakers, 1928–29.

charges made for selling the same product.—These variations cause invidious comparisons; the ordinary user is repelled by their complexity, and the result is a disconcerting brake on electrical development. Many undertakers appear to be selling electricity to consumers in quantities between 100 and 1 000 units per annum at prices greatly above the mean. These high prices for electricity, which at these low rates of consumption must be assumed to be mainly used for domestic purposes, while reflecting the enthusiasm of certain people for electricity, do not appear to display an enlightened policy on the part of the undertakers concerned.

TABLE 18.

Units sold to consumer	Increase in quantity	Consumer's bill	Increase in amount paid (about)
		£	
250	—	5·50	—
1 000	4 times	7·70	1·4 times
3 000	12 times	13·75	2·5 times
5 000	20 times	19·75	3·6 times

(4) *That* 43 *out of* 221 *undertakers are charging, on the average, prices varying between* 6*d. and* 1*s. per unit.*—The result of bringing all such charges down to 6d. per unit—an action the authors advocate—might be (and then only temporarily) to bring about a diminution in revenue. The action suggested might cause some temporary embarrassment to the 43 undertakers concerned, but any financial difficulty could not last long, as, on the lowered tariff, consumption should rise.

There appears to be no justification under any circumstances for charges amounting to more than a 6d. or 7d. flat rate per unit, except, perhaps, where an undertaker thinks that his role as a supplier of electricity ends in giving lighting supplies only. New customers, the obtaining of whom is the essence of good business, are normally small consumers at first; and small consumers, it has repeatedly been observed by those most competent to judge, cannot be obtained and satisfied or induced to increase their consumption of electricity unless they are offered supplies at a suitable 2-part tariff.

(5) *The curve indicates the possibility of forming a* 2-*part tariff purely on a quantity basis—from* 0 *to* 8 000 *units sold per annum.*—For domestic purposes the authors feel that, in the interest of sales in quantity, the time has come when little or no check should be placed upon the use of electricity by the kinds of restrictions at present imposed by reason of load factor or time of use. The amount of power available behind all supply equipment is now so great that any restrictions of this character, while perhaps useful in the early days of the supply industry, appear now to savour of pettiness. If the domestic load is to be built up with any speed, the greatest freedom of use should be given to the housewife and things made as simple as possible for her throughout the 24 hours.

In the case of supplies on a large scale for power or other industrial purposes, however, sales on a kilowatt and unit basis would appear to be still useful and appropriate, and the "time of use" element will still be brought into consideration in arriving at contract prices.

Tariffs.

Reference has been made to the need for a suitable tariff if high acceleration of development is to be assured. Suitability depends, among other essentials, upon (*a*) its simplicity; (*b*) the degree of close correspondence it has to the individual demand made upon the undertaking; (*c*) the extent to which it induces the customer to increase his custom; and (*d*) the consideration it gives to time of payment and the reasonable desires of the individual consumer.

Returning for a moment to the rural curve AB of which the formula is $(1\,140/x) + 0\cdot73$, where x = number of units sold, if all consumers, irrespective of demand, were charged a fixed sum of £4·75 per annum plus 0·73d. per unit, the rate per unit sold would be as shown by the curve AB. Such a tariff would not work in practice and it was evidently necessary to determine how, on the average, the incidence of the fixed charges fell on consumers of varying quantities of electricity. Sufficient data were not available in the rural returns, and recourse had to be made to other published data.

Consequently, an examination, on lines similar to that adopted for the rural returns, was made upon the results of operation during the 12-months period of 1928–29 from 355 local authority undertakers in Great Britain.

TABLE 19.

Form of "Service" and "Running" Charge.

Units	Total unit charge	Corresponding 2-part charge	
		Service	Running
	d.	£	d.
200	6·00	1·25	4·50
500	3·01	1·60	2·23
750	2·25	2·00	1·61
1 000	1·87	2·40	1·29
1 500	1·49	3·15	0·99
2 000	1·30	3·90	0·83
3 000	1·11	5·50	0·67
4 000	1·015	7·05	0·59
6 000	0·92	10·20	0·51
8 000	0·87	13·35	0·47

The method of calculating the formula proceeded as before and the resultant curve AB shown in Fig. 10, of which the formula is $(1\,212\cdot3/x) + 0\cdot93$, was plotted and the average charge indicated by the line CD at £5·05 was obtained.

Incidentally, it is interesting to see from this formula that a higher price per unit is obtained in (*a*) urban (principally) and rural (partly) areas than in (*b*) rural areas only.

By a process of splitting up the 355 returns it was possible to observe the effect on the average fixed and running charge per consumer (i.e. £5·05 and 0·93d.).

The results went to show that at a consumption of about 200 units per consumer the fixed charge was in the neighbourhood of 30s. and mounted quite definitely as the units sold per consumer increased, as indicated by the dotted line YZ.

The fixed charge, now more correctly described as a "service" charge, being determined, the running charge is purely complementary and is shown by the dotted curve WX.

Applying the results of this method of analysis to the rural returns, and assuming a maximum flat-rate unit charge of 6d. per unit, the form of a suitable tariff would be as shown in Table 19.

The chief interest of this analysis lies in the fact that both the "service" and the unit charge vary with the quantity used, the one rising and the other falling. For practical application both must be "stepped." The question then arises as to what method of stepping should be adopted for the "service" charge, i.e. whether it should be based on rateable value, floor area, lighting watts installed, or any other factor. Everything points to the advisability of its being in some way related to units consumed.

This is not the place to enter into a review of this important question, but for some domestic applications there are arguments to indicate the reasonableness of basing "service" charge upon meter size, this in turn being based on the average kilowatt demand likely to be made at the consumptions given.

The authors contemplate development within their Model Scheme under a form of tariff wherein the service charge rises and the unit charge falls as indicated above.

(9) Estimated Loading of Model Scheme.

It is now possible to bring into relationship in a condensed form the main factors affecting the total load which may be expected over a period of years. Table 20 enables this to be done and gives the extent of the area and the density of population per square mile. Also, year by year over 6 years, it shows (*a*) the number of consumers expected, (*b*) the units expected to be sold per consumer, (*c*) the total units sold, (*d*) the load factor, (*e*) the estimated losses, and (*f*) the load in kilowatts and units which are to be obtained from the grid, or other point or points of direct or indirect bulk supply. It will be observed that the amount of electricity to be purchased in bulk in the final year amounts to 9 746 kilowatts at a load factor of 23 per cent, corresponding to a demand of over 19½ million units. On this computation it is possible to proceed with the consideration of the incidence of the load within the Model Scheme, and subsequently to deal with the design of the equipment in detail.

TABLE 20.

Loading of Model Scheme.

Density, 150; 384 square miles; Premises, 34 per square mile; Total Number of Premises, 13 056.

Year	Degree of saturation (per cent of connections)	Total number of consumers	Units sold per consumer			Total units sold per annum to consumers	Losses (on units sold)	Electricity bought at point of supply		
			Domestic	Power	Total			Units bought	Load factor	kW bought
	per cent					thousands	per cent	thousands	per cent	kW
1	20	2 610	200	100	300	783	33⅓	1 044	12½	953
2	40	5 220	360	230	590	3 081	25	3 851	17	2 586
3	54	7 050	520	360	880	6 204	22	7 569	19½	4 431
4	63	8 225	680	490	1 170	9 623	19	11 449	21	6 224
5	70	9 140	840	620	1 460	13 342	18½	15 810	22	8 201
6	73	9 530	1 000	750	1 750	16 678	17¾	19 638	23	9 746

The loading table (Table 20) is based upon the possibility of 73 per cent of the inhabited dwellings being connected at the end of the sixth year (see Section 4). This should be noted because, for the purposes of determining equipment design, to be referred to later, 90 per cent of the inhabited dwellings have been assumed to have become consumers.

(10) Incidence of Rural Load: Capacity of Equipment of Model Scheme.

The Model Scheme is a theoretical lay-out conforming on the whole, as already explained, to average conditions as found in Great Britain.

In the design of any rural scheme it is impossible to arrive mathematically and step by step at definite conclusions, as there are so many interrelated variables. Care has been taken to see that ample equipment is included in the estimates to cope with the anticipated load, and that the cost of this equipment is such as to allow for an economically sound scheme. Much thought has been given to each item and the Model Scheme may be regarded as an indication of the possibilities of an average rural area, but it should be remembered that it is neither practicable nor possible to design all items in a textbook manner. It cannot be too strongly stressed that when designing a scheme it must be considered in its entirety. Plant must be projected for the whole area and must be adequate for present and future needs. Whether or not it is all put down at once should not affect the lay-out. It may appear, and even prove in the earlier days of construction, more lucrative to depart from the general framework of the design, but this is bound to react to the detriment of the whole scheme when the final arrangements are about to be completed. This mode of approach to finality is by far the cheapest way in the end of developing an area, the old method of sporadic development being open to many pitfalls.

In the preparation of the Model Scheme it is necessary to determine at what points and to what extent load may be expected, then to estimate the cost of the high-tension and low-tension equipment, and finally to observe the effect on the cost of varying density of population.

While the problem of rural electrification on the distribution side is essentially an extension of the urban problem, the chief difference between a rural lay-out and an urban distribution scheme is that in the former case not only does density of population vary but there is a wide diversity of sizes of substations, and there is no possibility of interlinking on the low-tension networks. In urban areas the load density is more or less uniform, while the substations are of the same general size and interlinking is general. A rural area cannot be regarded in detail as an urban area stretched over a larger territory.

The size of the area selected for consideration, viz. 400 square miles, is an economical and workable one. Any smaller area will place too close a limit upon the expenditure available for propaganda and advertising. Smaller areas will, in addition to crippling administration, prove a bar to the employment of a highly skilled staff, and will not diminish the difficulties of control and operation. 400 square miles of territory, although fitting in fairly satisfactorily with the general grid scheme, must not, however, be regarded as a maximum area that can be worked satisfactorily.

Incidence of Electrical Load.

The total electrical load to be expected on the Model Scheme has already been given. This load can be roughly divided among three classes, viz. (*a*) villages, (*b*) isolated loads, and (*c*) industrial loads.

(*a*) *Village loads* are normally domestic loads. They must necessarily vary in amount, depending upon the size of the village, and are dealt with in the Model Scheme by assuming one load of this nature per parish (which on the average, as has been pointed out, covers an area of 4 square miles).

(*b*) *Isolated loads* include farms, mansions, country houses, hospitals, etc., and it has been assumed for the purpose of this investigation that there are four such isolated loads per parish—this having been found a reasonable number to take on the average. The total of the four isolated loads may be assumed to be approximately 20 kVA per parish.

(*c*) *Industrial loads.*—As to industrial loads it has been assumed for the purpose of equipment design that approximately 50 per cent, as against 43 per cent for revenue, of the total load in a rural area may be taken as industrial load. Owing to the difficulty of allocating the exact position of this class of load in the Model Scheme, it has been spread out and a fixed amount has been allocated to each parish—obviously a course which, in estimating costs of equipment, will call for a maximum capital expenditure. The mains have been designed to carry the load so disposed, and the necessary substations and equipment generally have been taken at an average cost on a kVA basis.

Turning to the subject of the village load, it is necessary to determine to what degree the population within villages varies, on the average, within the 400 square miles of territory under consideration. Some guidance may be found in an appendix to the Report of the Conference of Electricity Supply in Rural Areas, 1928,* which gives the scale of population of parishes in England and Wales and the number of parishes under each scale (see Extract, given in Table 21).

TABLE 21.

England and Wales.

Type	Scale of population of parishes	Number of parishes
A	Up to 100	2 151
B	101 to 250	3 510
C	251 to 500	3 176
D	501 to 750	1 438
E	751 to 1 000	761
F	1 001 to 2 000	1 120
G	2 001 to 3 000	409
H	3 001 to 4 000	159
I	4 001 to 5 000	71
J	Over 5 000	131
	Total ..	12 926

From Table 21, parishes of the smaller types have been selected in sequence, excluding the H, I and J types, i.e. all parishes having a population of over 3 000 have been excluded. In order to arrive at a population density of 150 for the Model Scheme area a certain percentage increase in the population within the parish has been added, as shown in Table 22.

TABLE 22.

Type of parish in which village stands	Number of types in rural England	Percentage of types	Average population per parish to give a density of 150	Number in Model Area of 400 square miles
		per cent		
A	2 151	16·6	60	16
B	3 510	27·2	210	28
C	3 176	24·5	450	24
D	1 438	11·1	770	12
E	761	5·9	1 000	4
F	1 120	8·1	1 800	8
G	409	3·13	3 000	4

Any villages larger than those shown in Table 21 are regarded as being, for the purposes of the Model Scheme, semi-urban in character and are not included.

The method of arriving at the transformer kVA installed is as follows. From the units sold in each type of village for domestic purposes, i.e. 1 000 units per consumer for the sixth year of operation, the maximum demand is calculated on the assumption of a 20 per cent load factor. The transformer capacity (in kVA) is taken as 75 per cent of the maximum demand so obtained. This is the general method adopted in the Model Scheme for any size of village demanding a load above 25 kVA. For the smaller villages diversity of demand becomes a more prominent feature, and consequently the size of transformer becomes relatively greater and more a matter of experience than calculation. For the type A village referred to in Table 23, which has 12 consumers, a 15-kVA transformer has been chosen. Working on a 20 per cent load factor, a transformer to deal with the 3·35-kVA load actually estimated would appear to indicate the use of a 5-kVA transformer, but this size would be useless to cope with even a small cooking load.

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* Electricity Commission: Report of Proceedings of Conference on Electricity Supply in Rural Areas, 1928.

Table 23 also gives the type of villages and the number of consumers expected per village for maximum loading purposes, the covering figure being 90 per cent of the inhabited dwellings, as compared with 73 per cent taken when calculating demand and revenue in a former section of the paper. In taking 90 per cent for estimates of full demand it has been assumed, as is frequently the case, that 10 per cent of the dwellings are situated and so occupied as to be economically impossible.

Column 3 (*a*) gives the size of the village substation, column 3 (*b*) the isolated loads, and 3 (*c*) the portion of the industrial load allocated to the parish. The fourth column gives the total load within the parish, and the maximum the equipment must be capable of carrying, within the parish. This is extended to column 5, which indicates the capacity of the equipment installed in the Model Scheme area of 384 square miles, and aggregates 15 364 kVA.

TABLE 23.

Type 1	Number of consumers per village* 2	Parish equipment installed. Transformer ratings 3 (*a*)	 (*b*)	 (*c*)	Total maximum demand that equipment can safely take per parish 4	Number of parishes	Total maximum kVA demand on equipment (384 square miles) 5
		kVA	kVA	kVA	kVA		kVA
A	12	15	20	35	$70 + 33\frac{1}{3}\ \% = 94$	16	1 500
B	43	25	20	35	$80 + 33\frac{1}{3}\ \% = 106$	28	2 968
C	92	50	20	35	$105 + 33\frac{1}{3}\ \% = 140$	24	3 360
D	157	75	20	35	$130 + 33\frac{1}{3}\ \% = 173$	12	2 076
E	205	100	20	35	$155 + 33\frac{1}{3}\ \% = 210$	4	840
F	369	200	20	35	$255 + 33\frac{1}{3}\ \% = 340$	8	2 720
G	610	300	20	35	$355 + 33\frac{1}{3}\ \% = 475$	4	1 900
					Totals	96	15 364

(*a*) = Village load. (*b*) = Isolated load. (*c*) = Industrial load.

* The total number of consumers to be expected in the parishes concerned, according to this "equipment design," is 11 700, representing 90 per cent of the total number of dwellings within such parishes. According to the loading table for revenue, the number of consumers by the end of the sixth year has been assumed to be 9 531.

The Lay-out.

The general lay-out of the Model Area of 384 square miles of rural area plus 16 miles of urban area, making the total of 400 square miles, is shown in Fig. 11. From the centre of the area radiate four 33 000-volt lines, and the ends of these form the feeding points in each of the four areas of 100 square miles. Each quarter is identical, and in the full area of 400 square miles there are placed the four urban centres. The latter are shown in the centre of each 100 square miles, and it is from such centres that the 11 000-volt distribution lines radiate. As to the four urban areas, the cost of distribution and revenue returns have been omitted in the Model Scheme. Supplies of electricity are assumed to be given at the

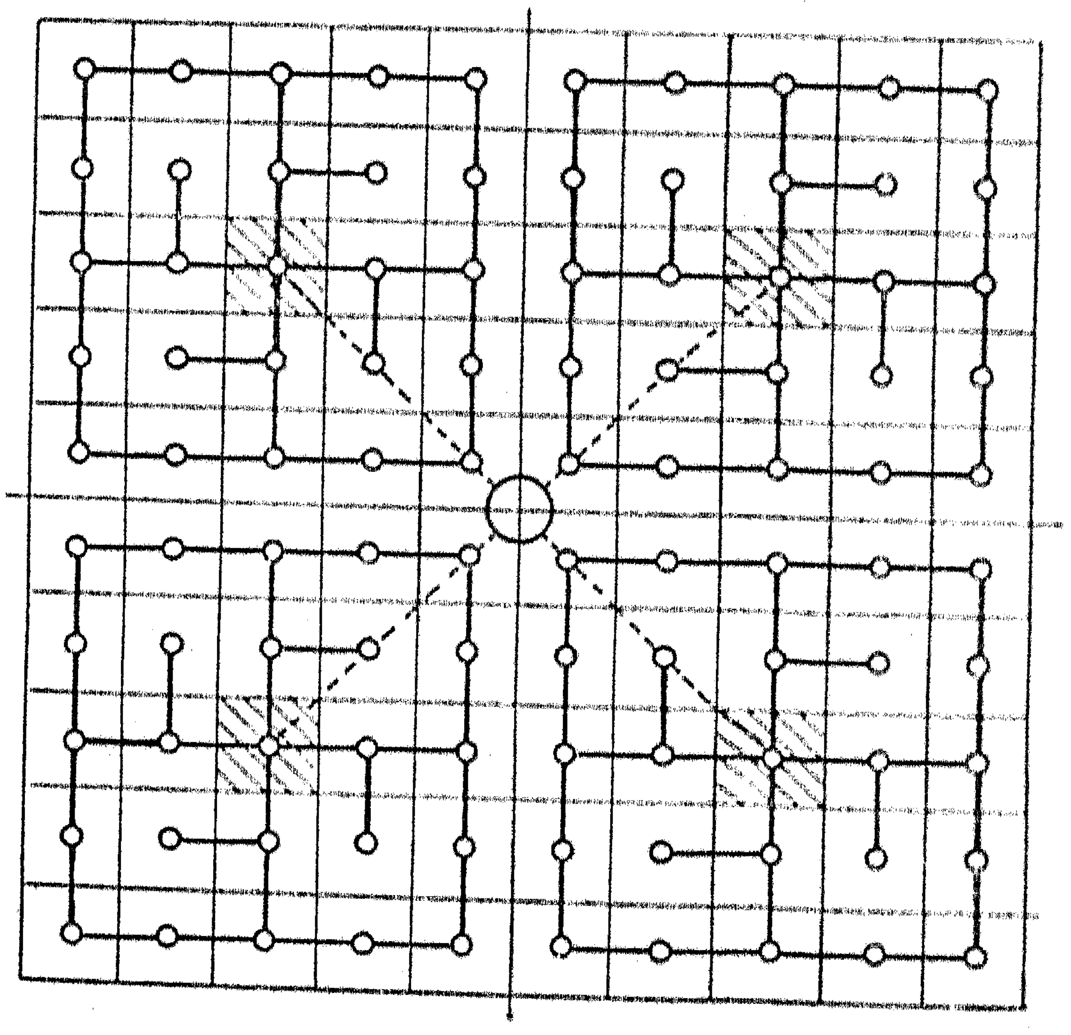


FIG. 11.—Diagrammatic lay-out of a model rural area of 400 square miles containing 100 parishes.

centres of the four 100-square-mile quarters and the cost of the supplies is inclusive of all charges and costs on the 33 000-volt mains and the 33 000/11 000-volt substations.

The size or type of a village and the number of villages of each size found in rural districts of the average density of population taken follow fairly definite proportions, as shown in Table 22. One of each type has been placed haphazard in a square on the diagram, the type being denoted by a letter (see Fig. 12), and the adjacent figures indicate the total maximum load in kVA estimated at the end of six years.

H.T. Interconnection.

There are many possible methods of interconnecting the loads thus disposed, the best being to adopt main radial feeders and then to interconnect the villages most remote from the centre and so form an outer ring. This ring, with the four feeders, forms four rings. Should the load necessitate it, an inner ring can easily be built, or, again, should the load become excessive in any particular part, a diagonal feeder can be run out to strengthen the network in that direction. Each 100 square miles of area having been assumed to be the same, it is only necessary to consider one for the purpose of arriving at the size of h.t. lines. Distortion of lay-out will occur in practice, but will not materially affect the design or the amount and cost of equipment needed.

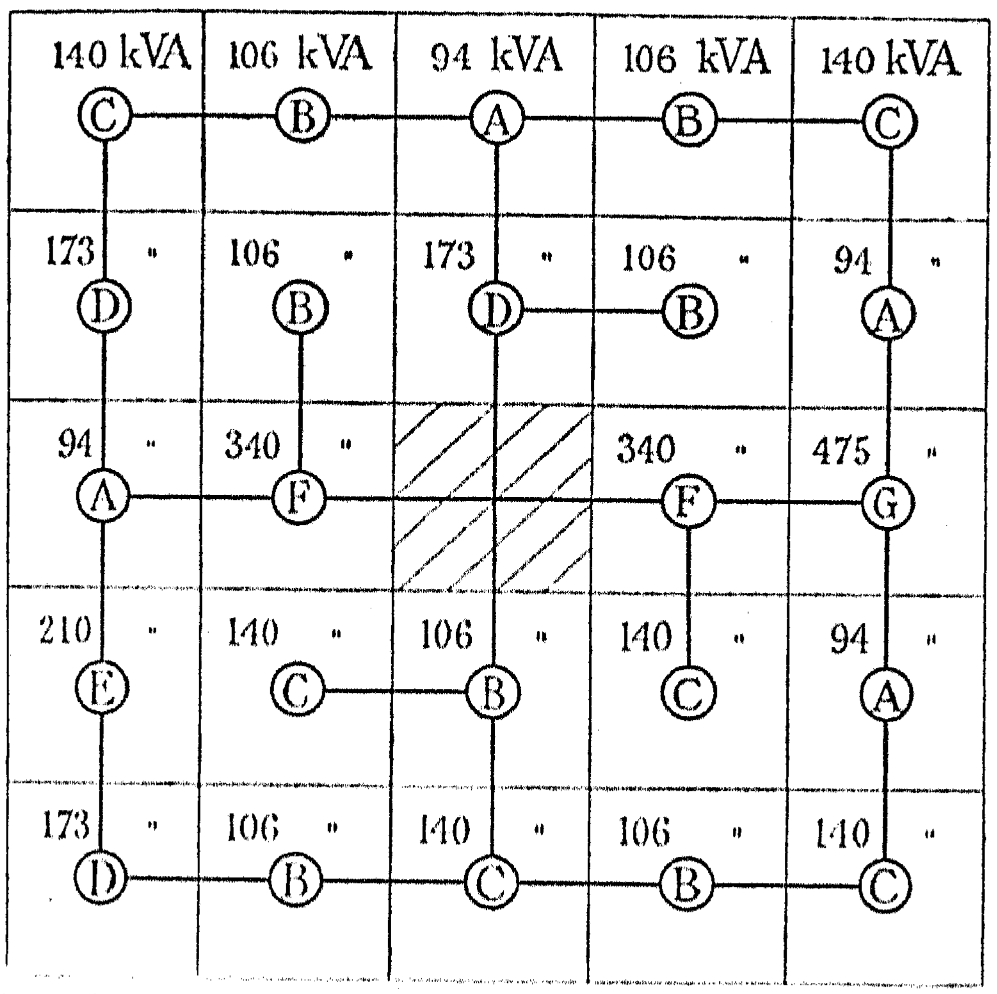


Fig. 12.—Diagrammatic lay-out of one-quarter of a rural area—100 square miles.

H.T. Voltage-drop.

Generally speaking, the size of conductor to be adopted is governed by voltage-drop. For the purpose of calculating voltage-drop in the various networks of the lay-out, it is useful to assume that the outer ring is disconnected at each radial feeding point.

The subsequent selection of a suitable conductor size would be made by trial and error, as set out in a later section of the paper, but taking, for example, a single circuit of 3-phase 0·05-sq. in. conductor at 11 000 volts, the loading on, say, the top member of the lay-out gives roughly a voltage-drop of 3·7 per cent, and going round in a clockwise direction the other members will give drops of 5·7, 5·2, and 4·7 per cent respectively. It is sufficient to note that at maximum load, and on the assumption that the outer ring is intact, there will be a tendency to balance up, and in the example taken it may be safely assumed that the maximum drop will not be more than about 4·5 per cent. This is a reasonable figure, and it is expected that at the end of six years, when the scheme is working up to full load, the actual voltage variation will be even less than 4·5 per cent, in view of improved "off peak" load demands. The above figures are based on a power factor of 0·8, which is somewhat low.

Village Distribution Networks.

The second column of Table 24 gives the length of l.t. distribution in each type of village. This length has been calculated from Fig. 13A, the curve being obtained by plotting the length of distribution line against the population of many villages. It is natural that the greater the population the closer together are the inhabited dwellings situated, and so, after a definite population, the length of l.t. main per head of population becomes almost a constant.

TABLE 24.

Type	Length of low-tension distribution	Conductor size
	ft.	
A	1 500	No. 8 S.W.G.
B	3 680	No. 8 S.W.G.
C	4 600	0·05 sq. in.
D	5 950	0·10 sq. in.
E	7 500	0·10 sq. in.
F	12 600	0·10 sq. in.
G	21 000	0·10 sq. in.

The authors have tried many methods of arriving at a reliable figure. One was to set out model villages for the different types, but this eventually proved unsatisfactory. The curve strikes a good average and the total cost of distribution ought to compare quite well with actual practice, there being little doubt that the above figures are reasonably representative.

To arrive at the conductor size, it was assumed that the transformer station was in or near the centre of the village, the load being evenly distributed. This method was employed for villages up to size F. For the larger villages, these being more compact, it was assumed that two or more feeders would be led from the substation and form a network, the network and number of feeders being so arranged that there would be no need for a greater conductor size than 0·1 sq. in. This can invariably be arranged. Working on this basis the cost of the l.t. distribution for the larger villages will be on the high side because, more often than not, lengths of smaller conductor lines can be used successfully.

Isolated Load Connections.

It has been assumed, for the purpose of estimation, that each of the four isolated loads within the parish will require on the average a 5-kVA transformer, and that to reach them will necessitate, on the average, 211 miles of h.t. line. These lines are all taken as being 3-phase and either steel lines using 7/12 S.W.G. galvanized steel conductors, or light copper lines, depending upon which, in the circumstances, is the cheaper.

This, the isolated, type of load plays a very important part in rural electrification. In this country and also in America, the consumer is required to pay a portion of the cost of the line. In nearly all cases a minimum payment per annum is required. There is absolutely no doubt about the need to encourage this type of consumer, i.e. farms, country residences, schools, etc. This problem is referred to more fully under the heading of " Spur Lines " in the section of the paper which follows.

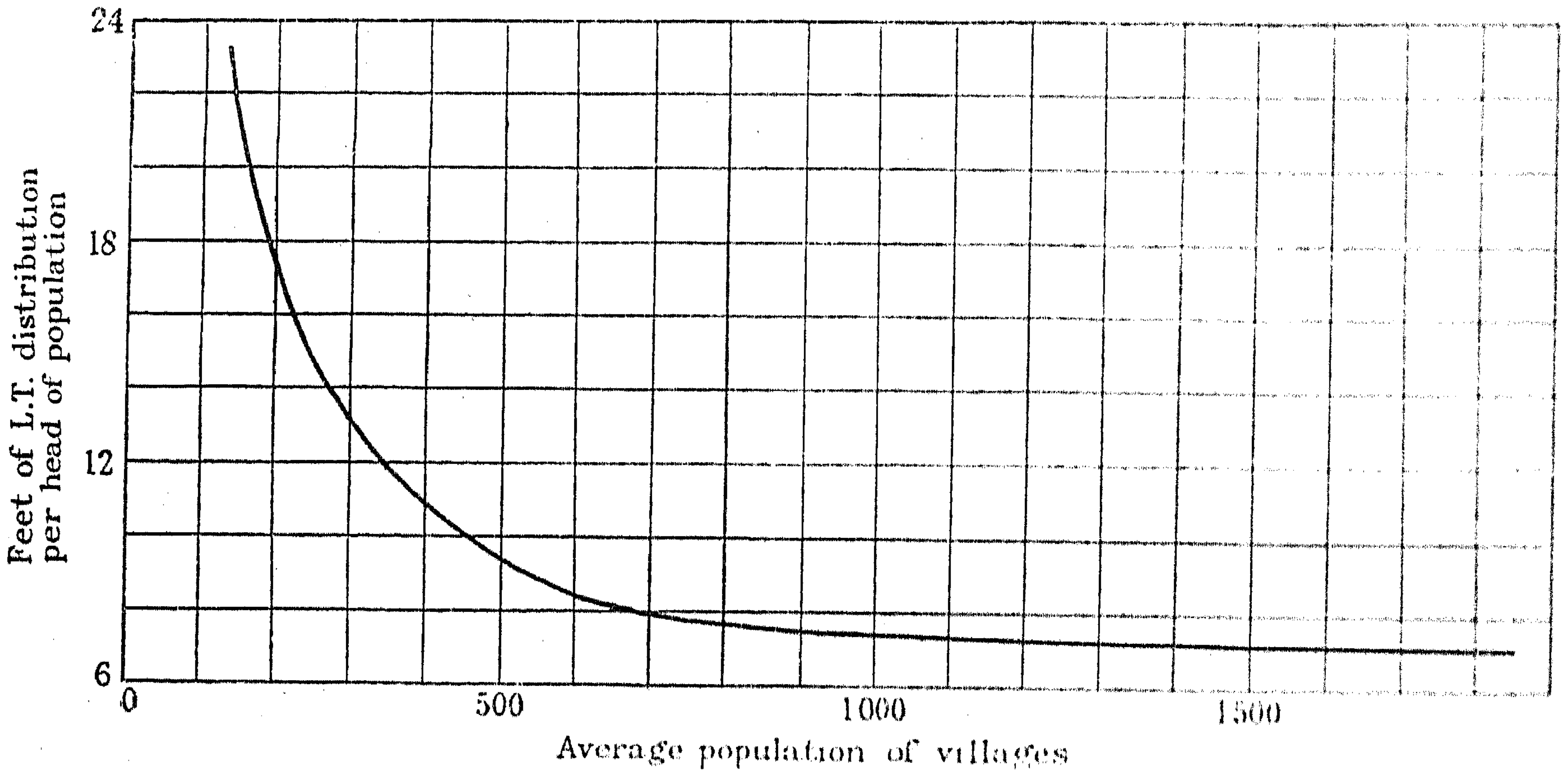


FIG. 13A.—Length of low-tension distribution mains in villages with population 0–2 000.

(11) MODEL SCHEME IN DETAIL.

General Considerations.

Having estimated the incidence of the load throughout the Model Scheme, we can now consider the Scheme in detail.

Existing practice will be reviewed, but only to show how rural conditions affect general design and to indicate the best and cheapest materials and types of construction to use for this kind of work. It will be convenient to consider this detail under the headings of h.t. transmission and l.t. distribution. As regards the former, underground cable has been ruled out in the scheme owing to cost, and with minor exceptions overhead conductors only will be considered.

As regards l.t. distribution, the authors have given consideration to underground cables, but, as will be shown later, cables are only practical in rare instances; consequently, overhead lines alone will be considered.

(A) HIGH-TENSION TRANSMISSION.

(a) *Choice of Voltage and Conductor; Voltage Regulation.*

Choice of Voltage and Conductor.—High-tension voltages available for rural work are 33 000, 11 000, 6 600, and 3 300 volts. It is safe to say that the higher the voltage the better will be the result, provided that t unduly raised, that the operating expenses do not prove excessive, and that safety and reliability are not sacrificed. In other words, the correct voltage is one which over a period of years will give the lowest cost.

It is possible that such considerations might result in the choice of a comparatively low voltage, e.g. where the problem is one of transmitting low-priced bulk supplies from one point to another and where the drop in pressure is unimportant. For rural work where the voltage-drop or regulation of the interconnected system of h.t. mains is one of the first considerations and where power losses in the line do not form the basis upon which the conductor size is determined, the designer must look to higher voltages for an economic solution. A limit will be found in this direction, however, as the load at the higher pressure may call for conductors of such a small sectional area as to preclude sound mechanical construction. Incidentally, it is under such light loading that a galvanized-steel conductor might be considered. Copper conductors below 0·035 sq. in. or above 0·1 sq. in. are as a rule unsuitable for light lines using wooden poles as supports and conforming to the Electricity Commissioners' Regulations, and they make the cost of lines outside these limits uneconomical (see Fig. 13B).

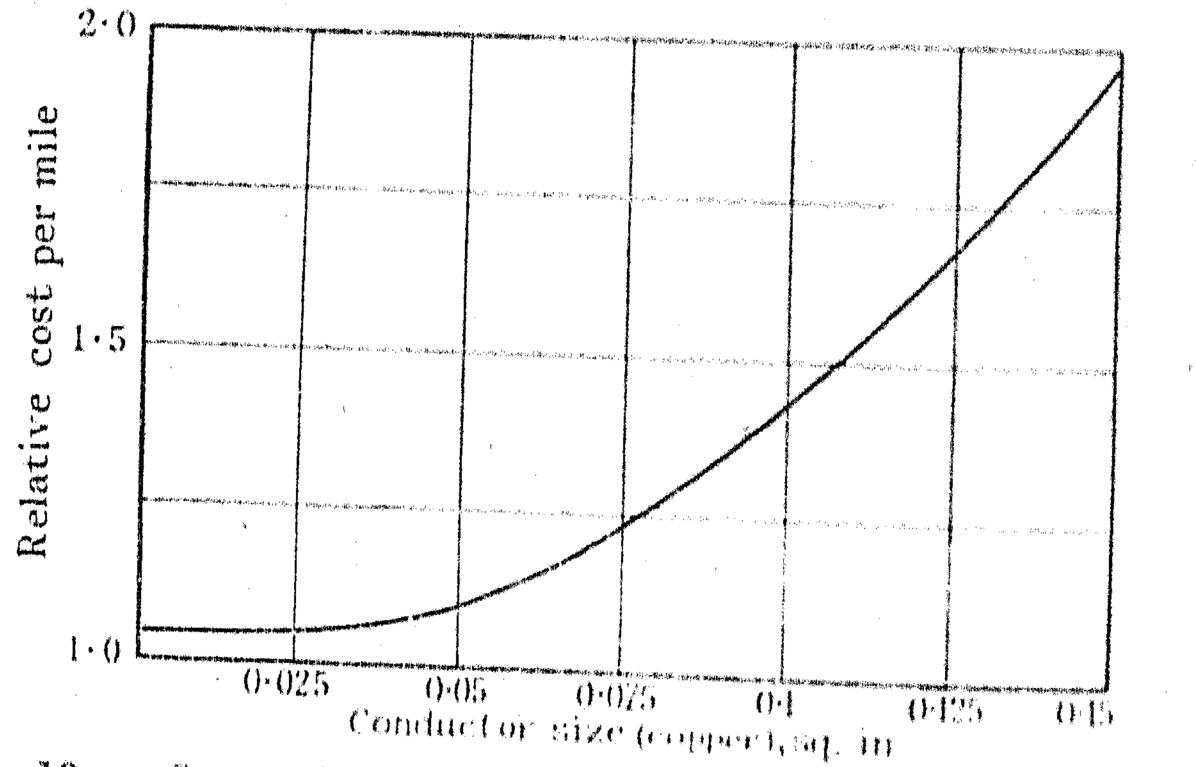


FIG. 13B.—Curve showing relation between cost per mile and conductor size for single-circuit 11 000-volt overhead line.

If the selected voltage is such as to call for a network with a conductor in excess of 0·1 sq. in., it is usually an indication that the voltage should be increased. Some time ago on certain of the larger rural electrification schemes in this country where the h.t. network is at 33 000 volts (the voltage of the C.E.B. secondary lines) it was felt that tappings at a voltage of either 3 300 or 6 600 volts would best meet the requirements of the small loads that were expected. A tertiary system of 6 600 volts appeared to give satisfaction at first, but loads increased and conductors of 0·1 sq. in. and over were soon called for. The cost of h.t. lines of such size was found expensive and, in consequence, was a deterrent to rapid development. With the same drop, a 0·05-sq. in. single-circuit overhead line of 11 000 volts will deliver 70 per cent more energy than a 0·1-sq. in. single-circuit 6 600-volt line, and is more than 20 per cent cheaper where the line is one using red fir single poles with pin insulators. Consequently, where development is, as at present, advancing, the choice between 6 600 and 11 000 volts is unquestionably in favour of the latter.

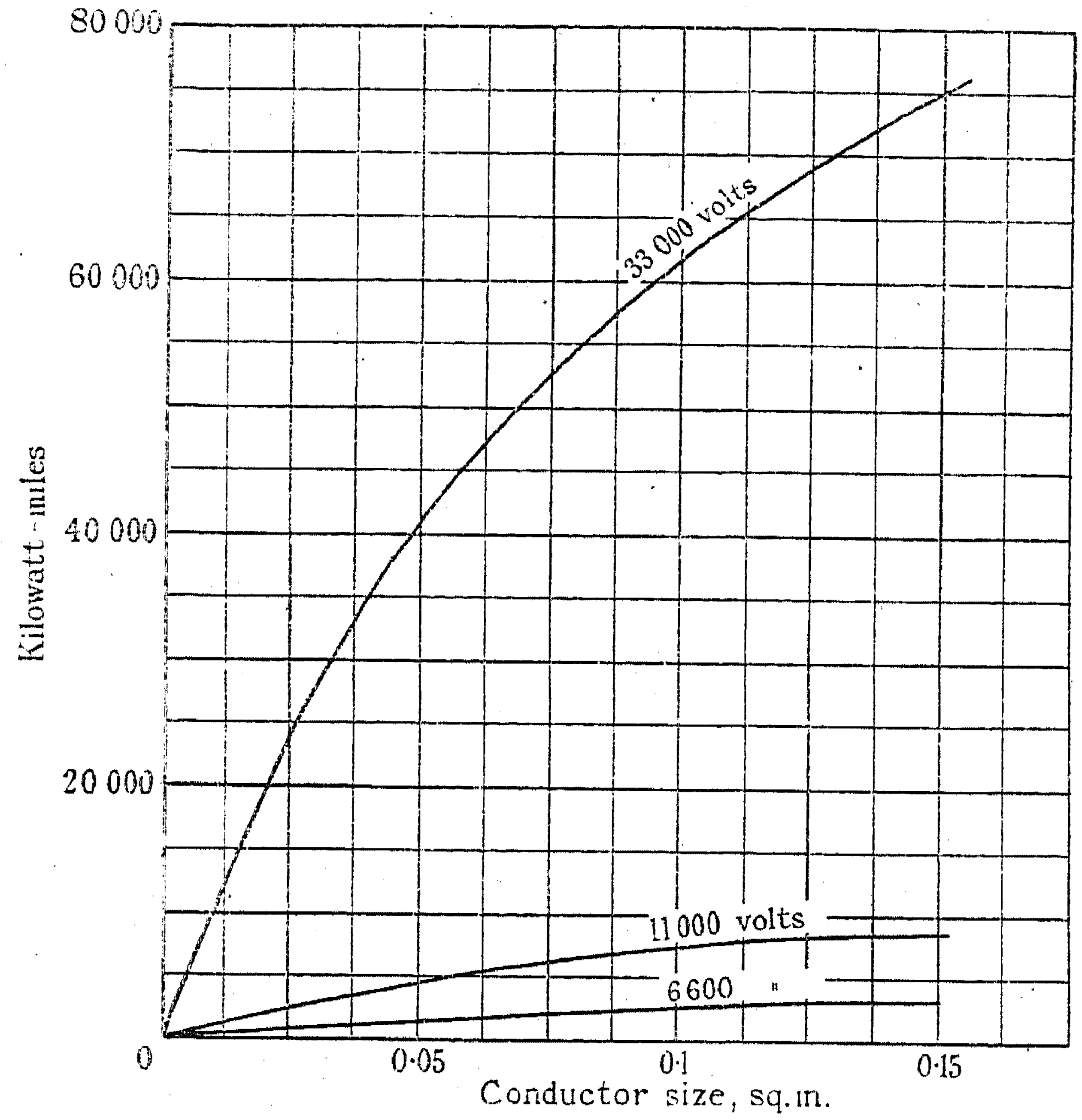


FIG. 14.—Curves showing relation between kilowatt-miles and conductor size for single-circuit 3-phase line.
Frequency = 50; power factor = 0·8; 6 per cent voltage-drop.

The above comparison, however, refers only to the transmission line itself, and any true comparison must take into account the increased cost of switchgear and transformers, both at the sending and receiving ends, for the higher voltage. Apart from any advantage that a voltage of 33 000 may have in special circumstances, the authors have come to the conclusion that 11 000 volts is generally the correct voltage for rural distribution work in this country. The advantages may be briefly summarized as follows:—

(*a*) There is little to choose between 11 000 volts and lower voltages from the point view of operation and reliability.

(*b*) The higher voltage presents no greater difficulty in insulation (either overhead or underground) than the lower voltages.

(*c*) Switchgear is only a trifle dearer for 11 000 than for 6 600 volts, and in any case is only a small proportion of the total cost of equipment.

(*d*) 11 000 volts lends itself to the distribution of sufficiently large amounts of electricity by means of a conductor the size of which (0·05 sq. in. section) makes robust overhead construction unavoidable and fulfils the requirement for economy in prime cost.

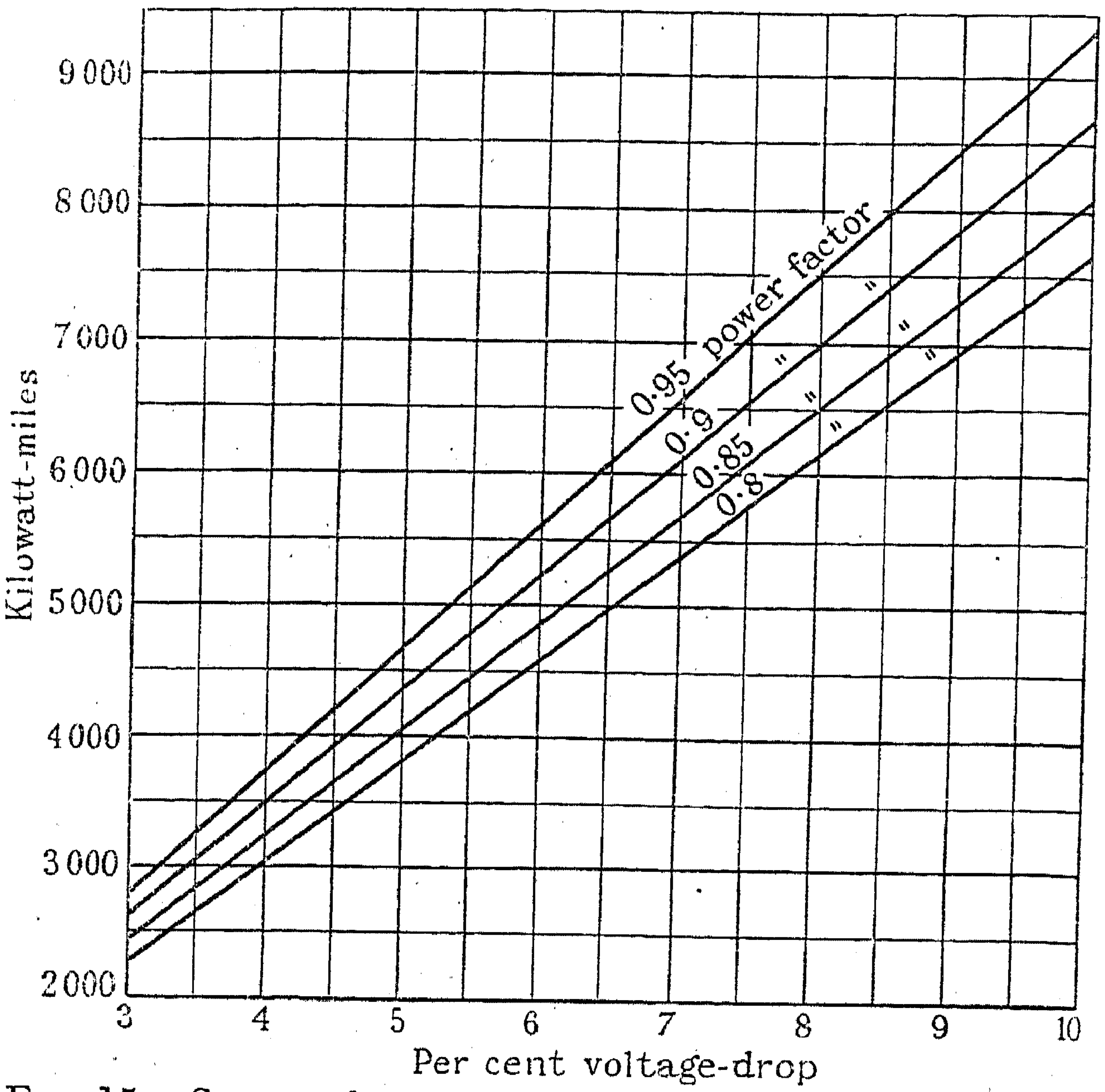


FIG. 15.—Curves showing relation between kilowatt-miles and percentage voltage-drop on 11 000-volt 3-phase transmission line.

Conductor cross-section = 0·05 sq. in.
Conductor spacing = 3 ft. 6 in.

The authors' review of requirements in the equipment of typical rural districts, having due regard to the distance between feeding points, indicates a load of between 3 000 and 4 000 kilowatt-miles. From Fig. 14 it will be seen that by the use of 33 000 volts a single-circuit line with a conductor considerably less than 0·0125 sq. in. copper equivalent is required; at 11 000 volts a conductor approaching 0·05 sq. in. is indicated, and at 6 600 volts a double circuit of 0·075-sq. in. conductor should be chosen. It will be clearly seen from Figs. 15 and 16 that an 0·05-sq. in. conductor is of ample section to carry 3 000 kW-miles.

As to the possible use of a 33-kV line, it is unsafe to erect such a line with a conductor less than No. 8 S.W.G. (0·022 sq. in. area); and, apart from this, it would prove expensive owing to the short spans it would necessitate. The cheapest 33 000-volt line must needs have a conductor of the order of 0·05 sq. in. (or equivalent area), and this, if of similar type and construction, would be about 10 per cent dearer than an 11 000-volt line, to say nothing of the switchgear, which would be approximately from 40 to 75 per cent dearer for the same line.

At this stage consideration may properly be given to a 33 000-volt line using a galvanized-steel conductor, or a steel conductor with a copper core, but it will usually be found that a line of this description is dearer than the 11 000-volt line, on account of the extra cost of insulation, larger conductor spacing, and switchgear.

Reverting to the chosen voltage of 11 000, Fig. 15 shows the kilowatt-miles that can be delivered with varying voltage-drop, and at varying power factor, by a 3-phase single-circuit 0·05-sq. in. conductor line.

Voltage Regulation.—The problem of keeping the voltage within prescribed limits at consumers' terminals is important. It is made difficult by reason of the fact that the transformers are connected to the h.t. ring main and that the l.t. distribution systems are connected direct to the secondaries, each system being unsupported by connection to any other l.t. system. Thus one should consider the voltage-drop in the three stages:—h.t. transmission system, transformer, and l.t. distribution to the consumer. A large variation in pressure at the consumers' terminals will have an adverse effect upon the working of motors and upon cooking; consequently, it will have a deterrent effect on the sale of electricity. It is, however, usually the case that, as the load builds up and the load factor increases, e.g. by the introduction of suitable tariffs and the development of all-night water heating, the voltage variation will become less marked and more easily brought under control. It is probable that satisfactory means of controlling exceptionally large variations in pressure in certain unforeseen circumstances will be found through the introduction of automatic voltage regulators.

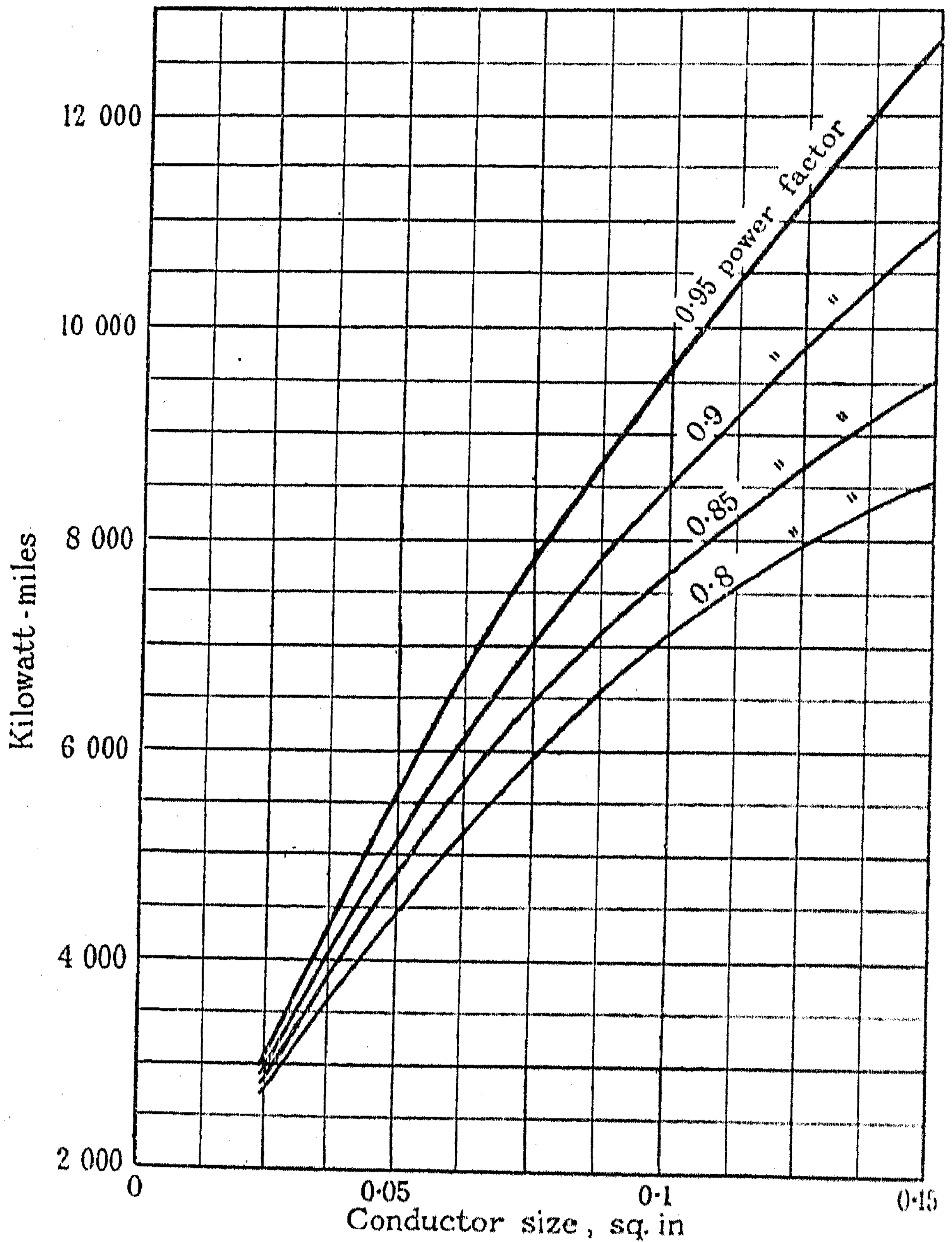


FIG. 16.—Curves showing relation between kilowatt-miles and conductor size on 11 000-volt 3-phase transmission line.

Frequency = 50; 6 per cent voltage-drop; conductor spacing = 3 ft. 6 in.

(*b*) *Conductor Spans and Supports; Tension of Conductors; Road Crossings and Protection.*

All the works considered in the Model Scheme are designed to comply with the Electricity Commissioners' Regulations. The more important of these with which we are concerned relate to (1) stringing of conductors, allowing $\frac{3}{8}$ in. radial ice loading plus 8 lb. per sq. ft. wind pressure, with a factor of safety of 2; (2) the loading of the support, allowing 8 lb. per sq. in. wind pressure on pole and ice-loaded conductors, with a factor of safety of 3·5; (3) earthing of metal work; and (4) precautionary measures at road crossings. These will be dealt with as they arise.

Conductor Spans and Supports.—Having determined the conductor size and transmission voltage, the next step is to decide upon the material to be employed, the type of support, and the normal span. These three are closely interrelated. There are, in addition, many other minor variables.

The topography of the area will influence the cost of the line. For example, an undulating countryside may prevent the use of spans of, say, 450 ft. Speaking in a general way, a span of 350 ft. has been found to be the economic span for 0·5-sq. in. copper equivalent S.C.A. (steel-cored aluminium) conductor; about 300 ft. for copper conductor of 0·05-sq. in. section; and over 400 ft. for the segmental type of S.C.A. conductor. In flat country, with only occasional road and railway crossings, spans may be increased, and in such circumstances a saving in cost will be shown. A long span is not so readily adaptable to topographical variations and constructional requirements, because provision must be made for transformer and angle poles in the run of the line. These supports are fixed points in the run and the other supports must of necessity be spaced to suit; consequently, more often than not, full use cannot be made of long spans. However, it cannot be too greatly insisted upon that the longer the span the better from all points of view, especially that of wayleaves. Steel-cored aluminium, whether it is ordinary strand or of the segmental variety, usually gives the cheapest line.

There is a general tendency to introduce steel lines with long spans; many lines have been erected with spans of 525 ft., a dimension which is almost unheard of outside this country. The two chief factors influencing this trend towards long spans are those of wayleave difficulties and the relaxation afforded by the Overhead Line Regulations when calculating the factor of safety, viz. a reduction of the radial ice loading from $\frac{1}{2}$ in. to $\frac{3}{8}$ in., thus permitting such spans on poles of normal size, e.g. 34 to 38 ft. long by 12 to $13\frac{1}{2}$ in. dia. While remembering that any line which requires the use of abnormal-sized poles is costly, long spans give slightly cheaper lines than those designed for 300- to 350-ft. spans, which were, until recently, considered reasonable for single-circuit lines. Many designers still adhere to a span of 350 ft., as it appears to be one most suited to the countryside. A long-span line is, as before stated, not nearly so adaptable to variations in ground-level as a short one, and a single additional support—especially if the line is short—may mean a larger percentage increase in the total number of poles used. The difficulty is that it is not always possible to make full use of the large span. Galvanized-steel conductors must, if full use is to be made of their tensile strength, with consequent long span, be strung up to a high figure (maximum 1 700 lb. for 7/14 S.W.G. and 3 000 lb. for 7/12 S.W.G.). Hence at angle and terminal positions much staying is required. The diameters of these conductors are large; consequently, fairly large poles are required to cope with the heavy loading. Although considerable saving is effected on the cost of the conductor, the rest of the construction is just as costly as for a 0·05-sq. in. copper line, or its equivalent in steel-cored aluminium. For steel lines it may be necessary to use strong pins of the 2 000-lb. size for the insulators, and the foundations of the poles require kicking blocks. Other disadvantages of galvanized-steel conductors are a short life and little or no scrap value.

TABLE 25.

Spans	Cost per mile of 11 000-volt single-circuit overhead line, 0·05-square inch conductors	
	Copper	Copper equivalent S.C.A.
ft.	£	£
150	535	515
200	469	442
250	452	409
300	425	397
350	413	375
400	416	367
450	423	377
500	446	385

As a fair compromise for the main transmission lines in the Model Scheme, a 350-ft. span with a steel-cored aluminium conductor on wooden poles has been chosen.

Supports.—There is great variety of choice in supports. The authors have considered the possibilities of steel, ferro-concrete, and wood. While the first-named finds its application in heavy transmission work, for the light work, which alone is being considered in this paper, the authors, seeing that a wooden pole at the present is so much cheaper, lighter, and more easily handled, than a pole of other material, recommended it on these grounds, and have therefore included such supports only in their Model Scheme.

The cost of the pole plays an important part in the cost of the line, but the cost of the pole is by no means proportionate to the pole size. Smaller poles, such as can be used on a 210-ft. span, are considerably cheaper than those required for a 360-ft. span, and, although the cost of poles per mile may be lower for the 210-ft. span, cost of insulators, erection, and wayleaves, may outbalance the saving and favour the longer span.

Table 25 gives the cost of overhead lines for various spans and for copper and steel-cored aluminium for a 0·05-sq. in. line with copper at £55 per ton and assuming reasonable facilities for erection and wayleaves within a radius of, say, 50 miles from any large manufacturing centre, and for a 20-mile run of line.

Probably reinforced concrete will in the near future be able to compete with wood in the essentials of first cost, ease of transport, durability, and maintenance, and when that time arrives the authors would recommend reinforced concrete.

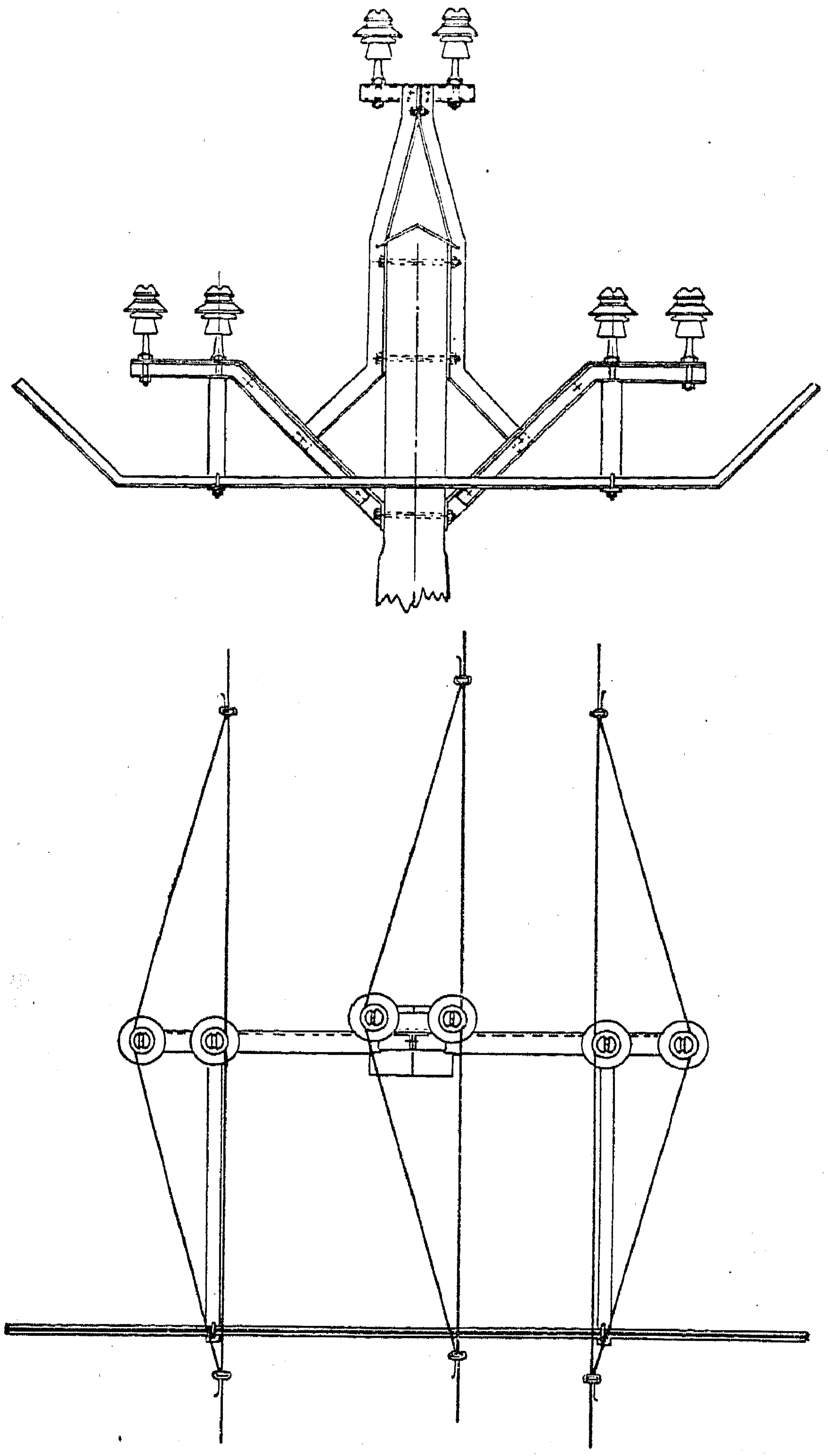


FIG. 17.

Road Crossings and Protection.—The usual practice is to fit double insulators, bridles, and earth bars, at the crossing poles. Spur lines cross public roads somewhat infrequently, so that road-crossing precautions do not enter greatly into the discussion.

Fig. 17 indicates generally the precautionary measures to be taken on overhead road crossings, using an intermediate pole and pin insulators.

(*c*) *Insulators and Earthing Arrangements.*

Insulators.—Little difficulty is experienced with insulation at 11 000 volts. Pin-type insulators have proved to be satisfactory. There are many such insulators on the market, most of them more than fulfilling the British Standard Specification. If the lines are near the sea or subject to winds coming from the sea, it is advisable to select an insulator rated higher than 11 000 volts. The use of suspension insulators on light- or medium-span 11 000-volt lines is unnecessary and can only be regarded as a costly refinement. When long spans over 525 ft., say of 650 ft., are used with steel conductors, pin insulators may not prove strong enough and suspension insulators should then be used.

Earthing Arrangements.—As to whether a continuous earth-wire should be installed, or each support be independently earthed, it may be observed that the latter method on spans of the length here proposed is about 5 per cent cheaper per mile, and this saving is an important consideration. From the points of view of reliability and freedom from electrical disturbance, it is now generally accepted that it is better to have a continuous earth-wire, but as comparatively few flash-overs and little damage are experienced from lightning in this country, it is doubtful whether it is worth the extra cost on light lines of this description. Independent earthing, therefore, has been adopted for the Model Scheme.

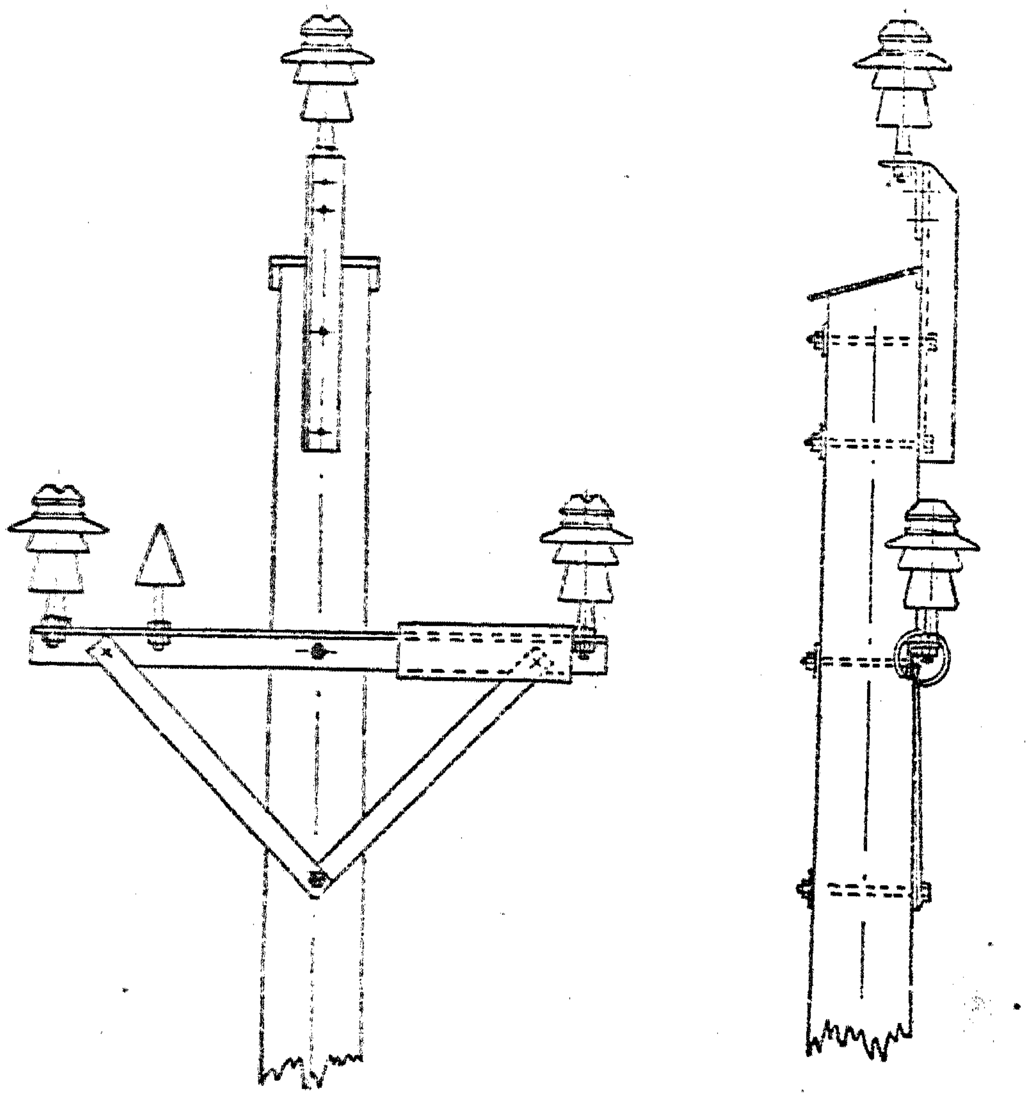


FIG. 18.

As to the type of earth-plate or earth-pipe to be employed, a cast-iron plate 18 in. by 18 in. by $\frac{3}{8}$ in. has almost by common consent been standardized, although 8-ft. rods appear to be more effective. Additional surface does not materially improve the earth-plate's effectiveness. Cast-iron earth-pipes 6 ft. long and 3 in. diameter are also used.

The authors' opinion is that either 18-in. square cast-iron plates or an 8-ft. by $\frac{5}{8}$-in. diameter rod meets all requirements.

(*d*) *Pole Fittings.*

Pole fittings should be standardized and the same construction used throughout any scheme, as cost is thereby reduced and a minimum of stock equipment can be carried.

There are several points to be remembered with regard to pole-top design:—

(1) The fittings should be robust and all ironwork should be hot-galvanized.

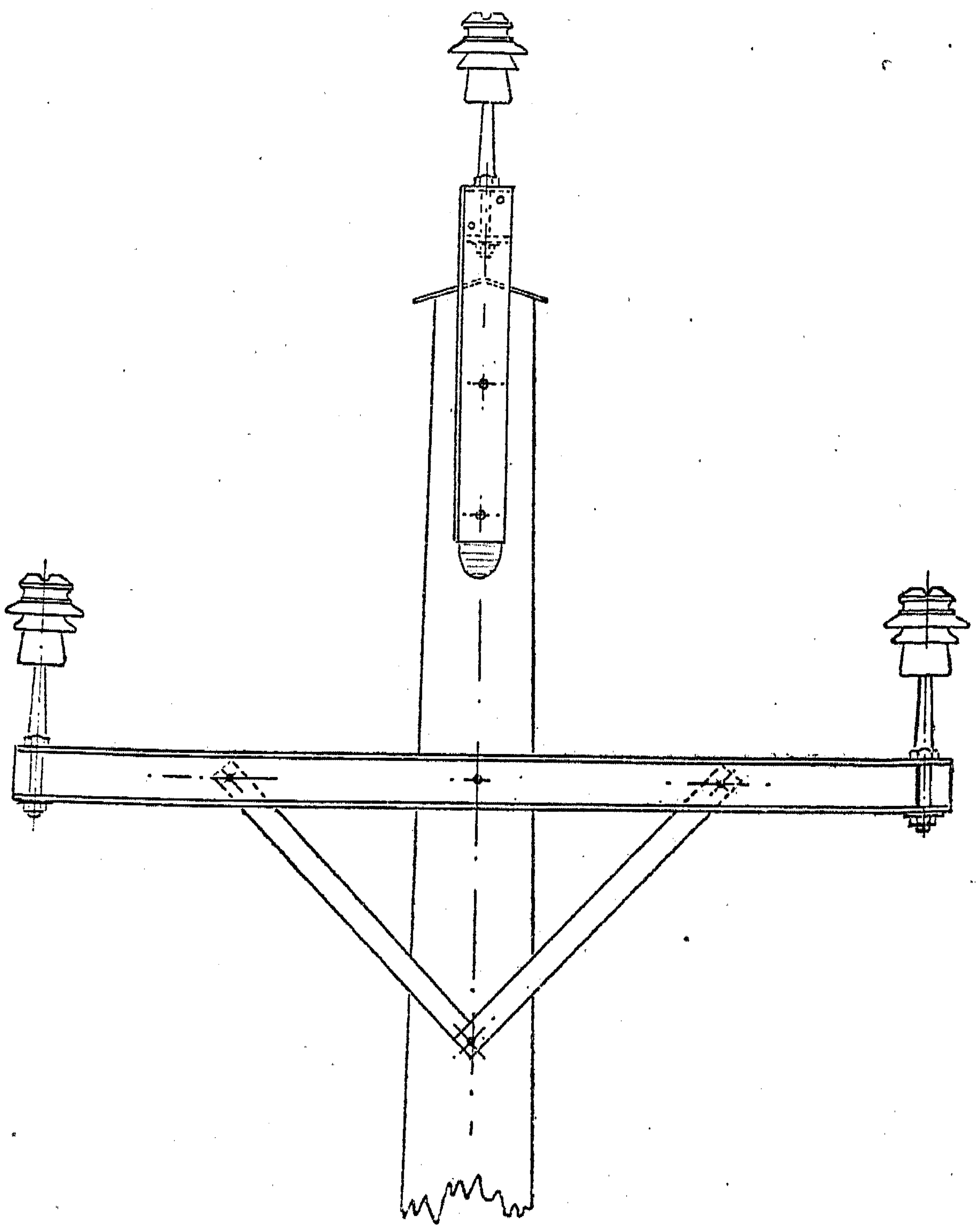


FIG. 19.

(2) The fittings should be such as can be fixed on the pole without undue scarfing and drilling of holes, and should be adjustable to poles of varying diameter.

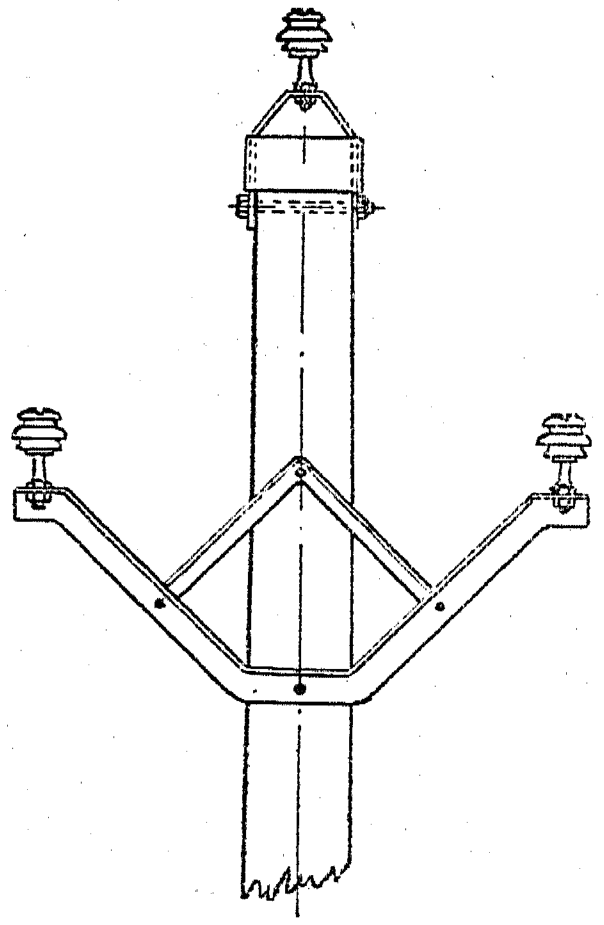


FIG. 20.

(3) One pattern of insulator pin only should be required for all positions.

(4) The number of parts and sizes of bolts should be a minimum.

(5) The fittings should be readily adaptable for road-crossing positions.

(6) The fittings should obviate trouble due to birds sitting on the cross-arm and coming in contact with the conductor, thus shutting down the line. Three well-known methods used for preventing this trouble are:—

(*a*) Bird guards fitted to cross-arms.
(*b*) Long stalks fitted to insulators.
(*c*) Sloping cross-arms.

(7) The fitting should be reasonable in cost and of good appearance.

Fig. 18 shows the type of construction embodying features (1) to (7) stated above, and in general use in this country; alternative forms of bird guards are shown. Obviously only the cross-arm requires a bird guard. In some cases, a fibre tube 18 in. long, as shown, is placed over the cross-arm and kept close to the insulator pin by means of a copper wire twisted round the insulator stalk. An alternative form of bird guard (also shown) consists of a conical insulator serving as an obstruction for the bird and preventing its perching too near the conductor. An advantage of the latter type of guard is that, at road-crossing positions, it can be replaced by the extra insulator which is required for duplicated suspension, the distance between the pole and the insulator being insufficient to accommodate a large bird. As an alternative pole-top bracket the one shown in Fig. 20 may be introduced with advantage, its recommendation being that at road crossings holes may be drilled through the sloping sides to accommodate the duplicate insulators. At medium-angle positions, where the angle is such as to call for the use of two pin insulators, two cross-arms may be placed back to back one on either side of the pole. Since, otherwise, strain insulators or other special construction would be required, such an arrangement is a saving. The great advantage of this general type of cross-arm is that it is so adaptable.

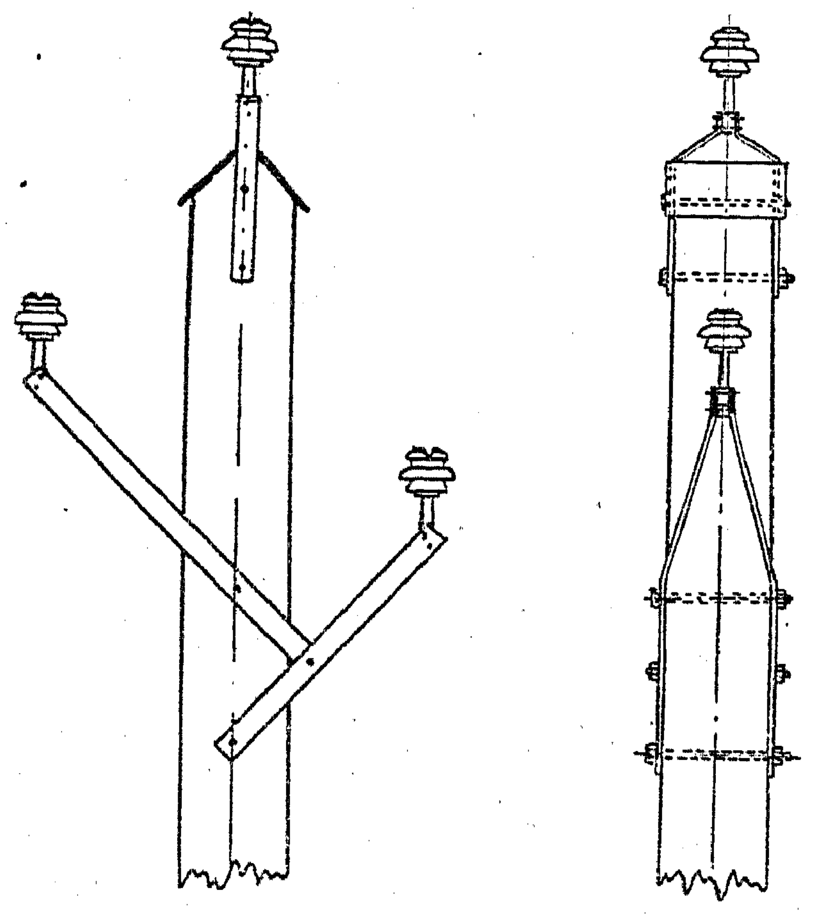


FIG. 21.

Fig. 19 shows a pole-top design which meets the same general requirements. In this design, pin insulators with long spindles are used as bird guards. The extra hole required at road crossings for duplicate suspension may easily be drilled in each arm.

Fig. 20 is a simple arrangement, pleasing to the eye. A cross-arm, bent as shown, is obviously more costly than a straight one, but against this extra cost that of the fibre tube or long insulator spindle bird guards must be taken into account. At road crossings, however, a special arm is needed.

Fig. 21 shows the type of construction used on the Bedford Demonstration Scheme. It is made entirely of galvanized flat iron, is robust, and is easily fitted to the pole. It has a novel feature, i.e. the insulator spindle is not threaded and fixed in position by means of a nut, but is secured by clamping the sides of the cross-arm to the part of the spindle below the shoulder.

Fig. 22 is the "herring-bone" type of construction and has several advantages. All members are of the same section and, being in metallic connection, do not require an interconnecting earth-wire; the pole alone requires drilling; and grooves are found to be unnecessary, as the fitting is held securely at four points.

There are many other pole-top designs, but on examination these will be found to vary in greater or less degree from the types illustrated.

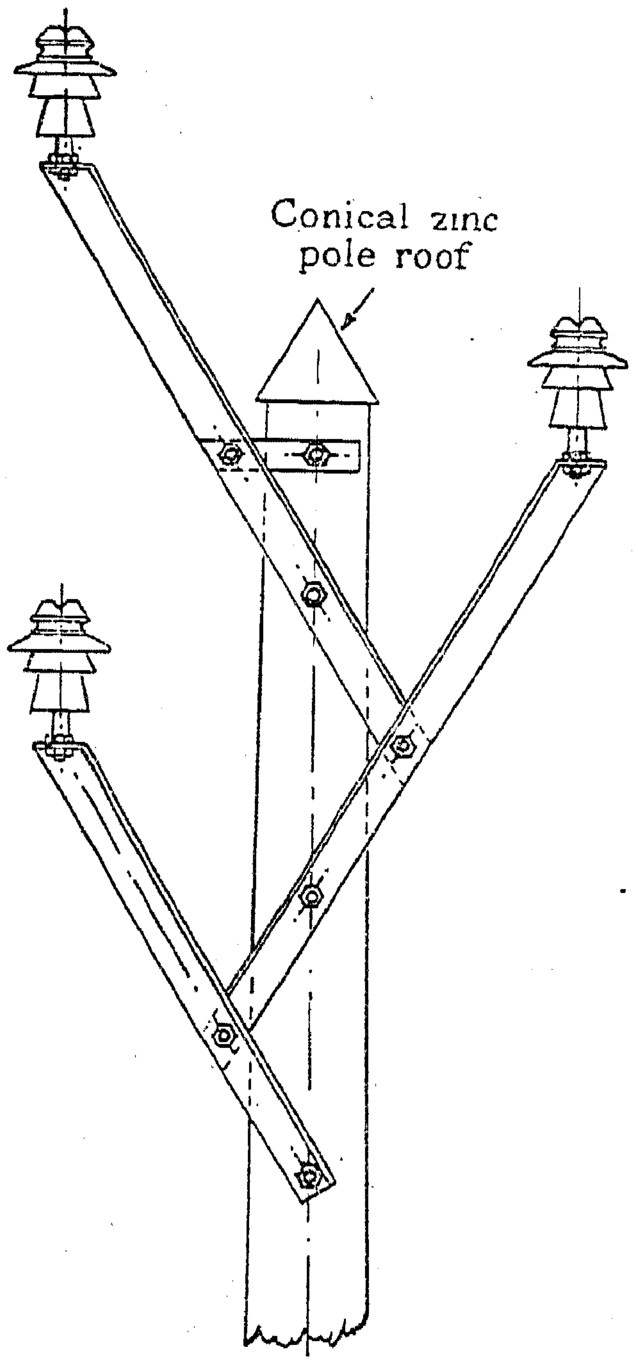


FIG. 22.

Of the designs shown, that of Fig. 18 is the cheapest and, in the authors' opinion, the best fitting, because it is easily manufactured, can be adapted to several different uses, is symmetrical and pleasing to the eye, robust, and the bird guards are effective and durable. It is on the basis of this design that the estimates which follow have been prepared.

(*e*) *Angle and Section Poles; Pole Foundations.*

Angle and Section Poles.—Angular variations in the direction of an overhead line can best be dealt with by using a stayed single pole, with the conductors in vertical formation, strain insulators being used. The jumper loops can be carried across in a straightforward manner, giving ample clearance between the loop and the pole. Section poles, if in a straight line, usually call for a light

"H" pole with the conductors strained off to a double cross-arm at the top of the pole, the conductors being in horizontal formation; such poles lend themselves effectively to staying. Section poles should be avoided at road-crossing positions.

Pole Foundations.—Lines of the size described must necessarily have reinforced foundations in any but the most stable ground. It is not sufficient to put the pole straight into the earth. Kicking blocks are essential in ordinary earth and should be arranged as shown in Fig. 23. It is difficult to state definitely the size of baulks as so much depends on the nature of the ground, but it can be assumed that a pressure of 30 lb. per sq. in. on the bottom baulk is a reasonable figure to adopt.

(*f*) *Spur Lines: Spans; Supports; Earthing Arrangements; Road-crossing Protection.*

Spans; Supports.—Spur lines are lines branching off from the main ring or transmission line for the purpose of connecting isolated consumers. Such lines are in all cases h.t. lines and, to avoid unnecessary transformation, should be of the same voltage as the main feeder. Sales to such isolated consumers are vital to the satisfactory electrification of rural areas and may ultimately constitute the major part of the rural load, yet in individual schemes it is difficult to estimate the extent of the demand. The undertaker is often called upon to erect from half to one mile of h.t. line in order to connect, say, a farm on which the maximum demand may not exceed 5 kW and the revenue from which may not be more than from £15 to £25 per annum. The approximate capital cost of a mile of 3-phase spur line is about £240. To this must be added £50 for transformer, fuses, etc., making a total of £290 or, say, £300, on which sum the undertaker might reasonably look for a return of £60 per annum in the sale of electricity. The problem is therefore a real one; great as may be the desire of the undertaker to obtain custom, he feels he should not do so at the expense of the remainder of his consumers, both village and power.

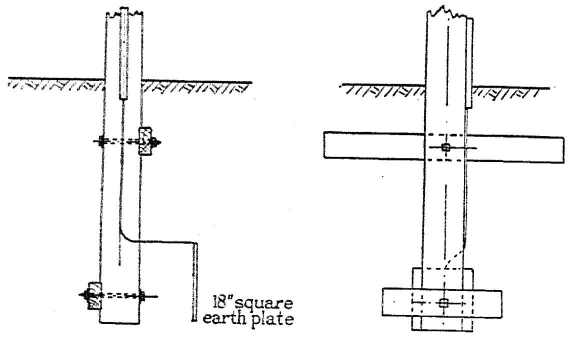


FIG. 23.

In considering this problem, comparisons are frequently made between our own and other countries where, it is stated, agriculture is much better served than with us. In France, farms are usually either on or just off the main roads, and as such roads are nearly always in a direct line from one village to the next the roadside is used for the h.t. line. In Scandinavia and Switzerland there is a tendency for farms to cluster in communities, thus rendering the solution easier. This feature of spur-line connection is rarely found in Great Britain, where, apart from two or three small farms on the outskirts of a village, capable of being connected to the l.t. village system, the farms are situated away from the main arteries and approached by accommodation or small roads. A cluster of four or five farms in close proximity to one another in open country is rarely found in this country.

Of the many suggestions offered as a solution, or part solution, of the problem, the following may be stated:—

(*a*) The obvious one of reducing the cost of the spur line.

(*b*) Arranging, in the original lay-out of the main h.t. lines, to pick up the maximum number of isolated consumers with a minimum of spur-line lengths without adding materially to the length of the h.t. main line. Considerable deviations from the straight route between villages add little to the cost of the main h.t. line.

(*c*) Allowing the farmer or a combination of neighbouring farmers or isolated consumers to erect the spur line according to Regulations, and allowing the use of local material.

(*d*) Regarding spur lines as constituting an essential part of the h.t. transmission system and charging all costs to the general account.

As to the possible reduction in the cost of the spur line, it is futile to suggest a standard form of construction for use in all circumstances, as local conditions play such an important part in the economy of overhead-line work and the points raised in the earlier part of this paper in respect of the cheapening of cost of overhead lines apply with equal force to spur lines. Odd bits of line are expensive to erect and the cost of transport alone, if not carefully watched, can rise to an alarming amount. If a spur line supplies a farm or institution, continuity of supply is of the utmost importance, and cheeseparing in the design and construction of the line must not be such as to jeopardize safety. One redeeming feature about the spur-line problem is that there are next to no wayleave difficulties since the line, in nearly every case, is on the consumer's property.

It is the authors' view that the best solution for this country will be found in the adoption of suggestions (*a*), (*b*), and (*d*). They realize that such a course as (*d*) may mean an addition of about $7\frac{1}{2}$ per cent to the capital expenditure and an increase of approximately 1·5 to 2 per cent in the cost of the unit. Nevertheless, they consider that it offers the best ultimate means of extending sales, and they have adopted it for their Model Scheme.

The electrical load is so light that the resistance of the conductor is too small to affect the choice of materials. Galvanized steel, 7/12 S.W.G., of, say, 45 tons per sq. in. tensile strength, with long spans, is most in vogue at present, but consideration should be given to steel combined with other materials, as well as to light copper lines with short spans of 200 ft.

Steel Lines.—Reference has already been made in this Section to steel lines and the call they make for long spans if the full reduction in the cost of the line is to be attained. For spur lines long spans are not always possible with short lengths of line; full use cannot be made of its advantages, and experience therefore suggests that steel, or steel combined with other conducting material, may not afford the ultimate solution.

Copper Lines.—Where the total distance is short, the course uneven, and wayleave difficulties absent, a light copper line using solid conductors of 0·035 sq. in. or less, spans not exceeding 200 ft., and small inexpensive poles, may conceivably be erected at a slight saving on the cost of the types previously discussed. The saving depends, among other things, upon being able, with the small span and low conductor tension, to eliminate strain insulators at angle, section, and terminal positions. The pole-top design for such a spur line as selected by the authors for the Model Scheme is similar to that adopted for the main 11 000-volt lines.

Earthing Arrangements.—The general question of earthing has already been dealt with and the arguments brought forward apply equally to spur lines. It has been suggested that for spur lines all earthing should be eliminated; by so doing there will be a definite reduction in cost, but it is doubtful whether it is worth it. Pole-top fires due to "creeping" are fairly prevalent in America, where earthing of metal work is not adopted. The authors advise the retention of earthing for spur lines.

Road-crossing Protection has also been dealt with and the remarks there made apply equally to spur lines.

In conclusion it must be said that under existing conditions there is little hope of reducing the cost of the overhead spur line except as regards the materials used. The best course, therefore, having due regard to local conditions, is to estimate the costs of various types of overhead line suitable to the purpose, to select the cheapest, and then to make an effort to standardize all fittings and buy in as large quantities as possible. Having regard to all these circumstances, the authors have decided to adopt for the Model Scheme spur lines of 3-phase single-circuit copper conductors, of short span, with pole-top fittings earthed at each pole by an earth-plate.

(g) *Transformers: Technical Features; Considerations of Cost.*

Technical Features.—In the design of transformers for rural electrification, the problem is to obtain certain desirable features of manufacture and operation, while not exceeding a reasonable limit of capital expenditure. Not only must inexpensiveness be attained without sacrifice of reliability, but there are other features of design which become of greater importance than in the case of industrial power supply, because of the large number of small transformer sizes involved and the low load factor experienced.

These requirements are to a great extent mutually antagonistic and their achievements involves the use of increased quantities of active material.

Briefly stated, the essentials are: (1) Reliability; (2) low core loss; (3) low magnetization current; (4) close regulation; and (5) suitable arrangements and design of tank, fittings, and terminals.

As regards (1), fortunately the reliability of modern British transformers is such that we need no alteration in design.

Considering (2) and (3), the necessity for low core loss is that most distributors in rural areas will purchase their supplies of electricity, and the aggregate core losses of the transformers in a scheme will have their effect upon the kVA demand, and more particularly upon the unit charge, as they will add appreciably to the running costs of the undertaking. Low core loss can be achieved by using a core of decreased section run at a high flux density. The high loss in watts per kilogram, combined with the small weight of the material used, results in a smaller total loss. Although a transformer of low loss can thus be made, this solution should not be used, for it involves a high aggregate of magnetization current, which has to be paid for on "kVA demand," and may also cause or increase troubles due to harmonics in the system. Consequently, low loss and low magnetizing current can only be obtained by careful design and low flux densities: an incidental result is that upward fluctuations in line voltage do not so greatly affect the magnetization current. The second and third requirements are therefore met by using a relatively large quantity of transformer steel, and that of the highest possible quality, i.e. best loss and permeability characteristics.

As to (4), closer regulation is necessary because of the line drop to which it is added. Owing to this requirement and to the handicap imposed upon the "length of mean turn" of the winding by the larger core, a somewhat inordinately large section of conductor has to be used, and a corresponding weight of copper.

As to (5), so far as the general design is concerned, transformers should be contained in weatherproof, steel tanks, which, up to and including 11 000 volts, will not need conservators. Hangers should be provided up to sizes of about 15 kVA for cross-arm mounting. Beyond this size and up to 50 kVA, supporting platforms are desirable, and larger sizes should be installed at ground-level.

Although tappings will only be changed seasonally, off-load ratio-changing switches are advantageous, as they avoid opening the tank in (possibly) wet weather. They are comparatively inexpensive.

As regards main terminals, opinion has been more and more growing in favour of bare connectors through porcelain bushings and projecting upwards. It is desirable so to arrange matters that it is possible to remove the transformer from its tank without dismantling the terminals, although this is not essential. The bushings must be well splayed and of sufficient length to prevent birds causing short-circuits.

An oil gauge and valve are unnecessary, but a thermometer is useful.

Winding, especially end-turn insulation, should follow normal practice, and, given these precautions, a lightning breakdown is rare.

Considerations of Cost.—Having examined some of the desirable technical features of a "rural" type transformer, the bearing upon cost should be considered. The core and windings will necessarily be expensive, and no economies can be made in the bushings. Frame clamping arrangements and coil supports may be cheap and very simple.

It might be thought that the tank could be cheapened, since the heat to be dissipated, with low losses and low power factor, will be little. Actually, however, up to about 50 kVA, tank size and oil quantity are ruled by the minimum clearances allowable. Above 50 kVA, and considering that full compliance with B.E.S.A. temperature rating is doubtful, some economy might be made.

The way in which such transformers can be cheaply produced is to have them standardized in output, voltage ratios, and general arrangement. If this were done, manufacturers could save considerably in design and drawing expense, and could manufacture in quantity. Moreover, during the slack manufacturing season transformers could be made for stock. The saving effected would be a real one and not made at the expense of quality.

Choice for Model Scheme.—Fig. 24 shows the percentage power loss of various standard sizes of 3-phase 11 000/400/230 transformers at varying load factors designed to British Standard Specification. From this a general idea may be gained of the losses which may be expected in a rural scheme having many low-powered units on the system. It emphasizes the necessity of making an effort to improve the load factor.

In view of the load factors assumed, for the Model Scheme the authors have decided to allow overloads of 25 per cent on B.E.S.A. ratings when choosing suitable sizes. In this connection it may be pointed out that the annual peak load will occur during the coldest weather.

(*h*) *Substations and Switchgear.*

A number of general arrangements of substations have been devised and are in use. Every one of the pole-type substations one sees has characteristics of its own. Bearing in mind that the keynote of substation design is simplicity, the isolating link, the fuse-link, the transformer, and the l.t. gear, should be assembled with a view to safety and accessibility. The method of fixing the transformer should be such as to facilitate changing, and the whole assemblage should have a neat workman-like appearance—it should not look like an afterthought.

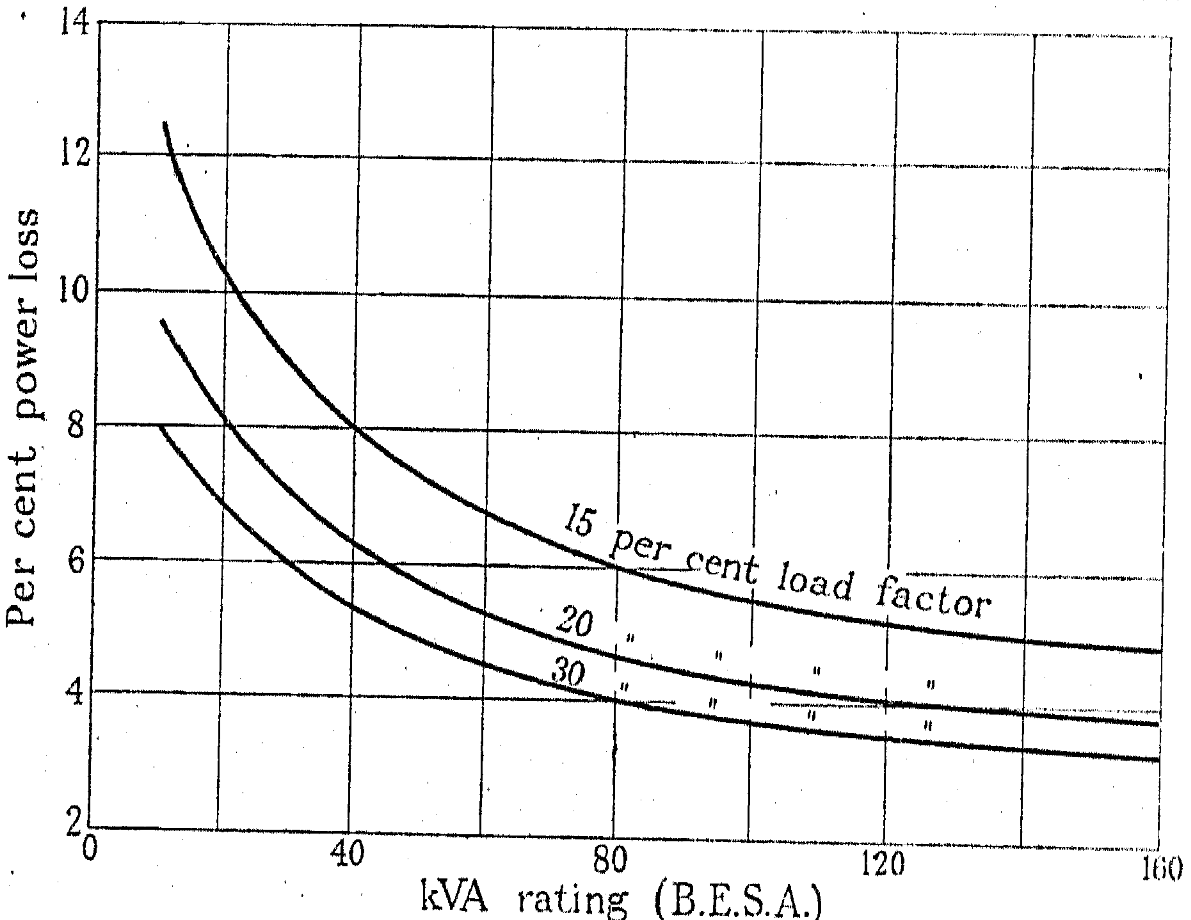


FIG. 24.—Curves showing transformer power losses.

In order that portions of the interconnecting ring may be isolated, it is essential to have a certain amount of switchgear. Such gear must at any rate be installed at the point where the radial feeder joins the outside ring. The authors have set out below what in their opinion are the essential features of design for rural substations of the following outputs: (1) 5 to 15 kVA; (2) 15 to 50 kVA; (3) 75 to 100 kVA; (4) 150 to 300 kVA and over.

(1) *5- to 15-kVA Substation.*—A 15-kVA transformer can be erected on a single pole. The h.t. tapping with the switchgear and transformer need not necessarily be placed on a terminal or section pole but can be attached to any pole on the line of route. The connection may be of the simplest and might be taken direct from the line to a link-fuse, and thence to the transformer. There are two methods of leading the l.t. conductor from the transformer:—

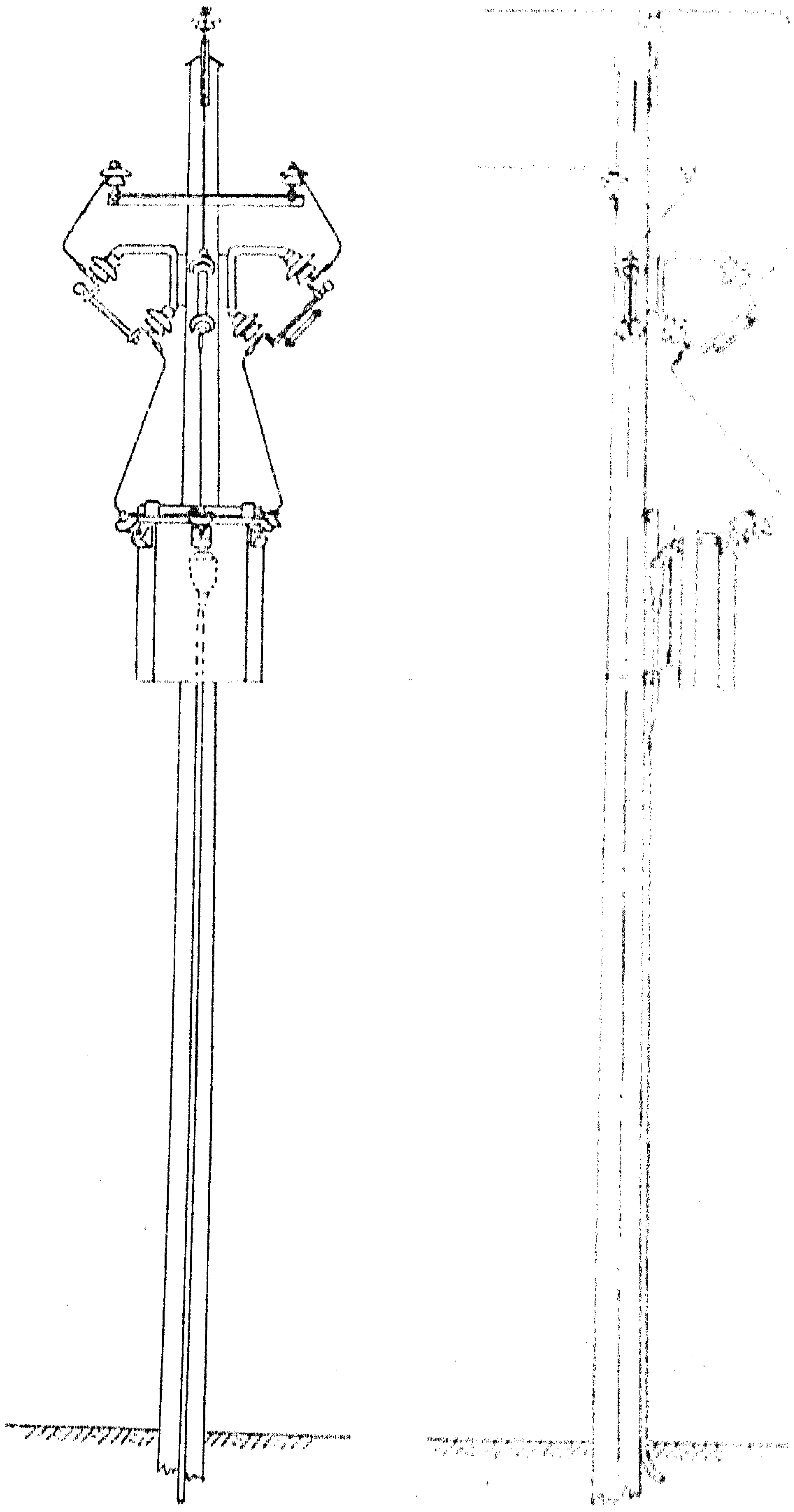


FIG. 25.—Transformer pole (5–15 kVA).

(*a*) In the case of an intermediate pole it may be the best method to run l.t. underground cable from the transformer to an independent l.t. network pole. This eliminates stays on the h.t. pole, but, nevertheless, requires them on the l.t. pole.

(*b*) To run bare overhead l.t. wires from the transformer pole direct to the l.t. overhead network. In assemblages of either of these methods the link-fuses should be operated by means of a rod from the ground. The h.t. tapping arrangement suggested is shown in Fig. 25.

(2) 15- *to* 50-*kVA Substation.*—A transformer can be supported, as indicated in Fig. 26, on a light platform between the legs of an "H" pole. The fuse-links should be of the "pull-down" variety. The l.t. leads are shown as being taken off from one leg on the "H" pole.

(3) 75- *to* 100-*kVA Substation.*—The suggested type of construction is shown in Fig. 27. If situated at a point in the network where it is advisable to sectionalize, a 2-way horn-break switch should be fitted at the top of the pole, the switch being operated by hand just above ground-level. From the centre of the switch a lead is carried to a "pull-down" type of fuse-link, from the bottom terminals of which it is continued to a cable box fixed to the pole, and thence by means of a h.t. cable to an outdoor transformer placed on a concrete foundation at ground-level. Close to the transformer a l.t. feeder pillar is installed from which l.t. 4-core cables can be led to the l.t. distributing system.

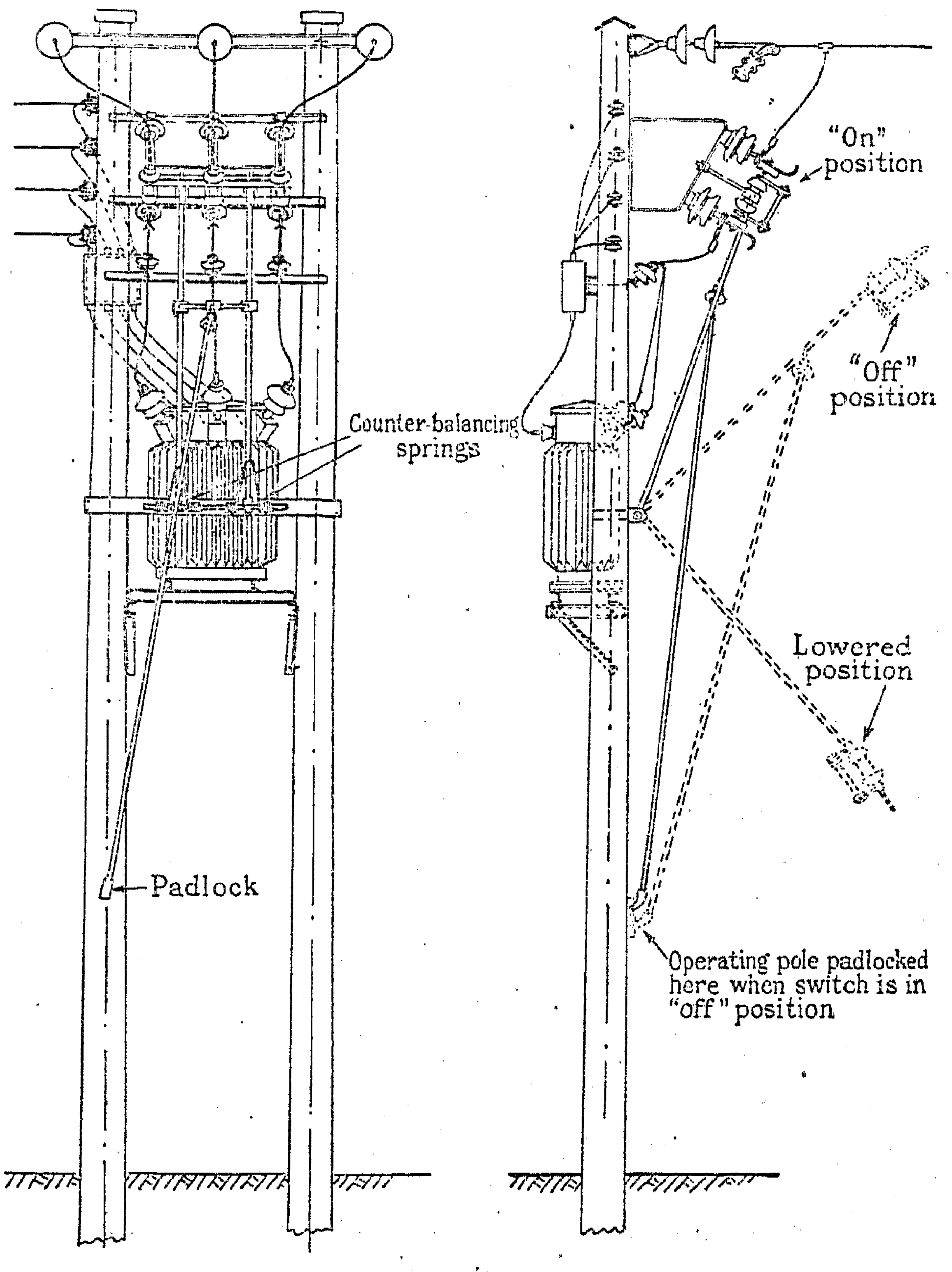

Counter-balancing springs
Padlock
"On" position
"Off" position
Lowered position
Operating pole padlocked here when switch is in "off" position

Fig. 26.—Transformer pole (15–50 kVA).

It is not good practice with such an arrangement to take several l.t. circuits from an "H" pole or from any 3- or 4-pole structure; it may be done, but it is unsightly and inconvenient. The use of short lengths of cable under such circumstances makes a tidy and satisfactory job. Low-tension fuses—a necessary part of the equipment for protecting the transformer—can be installed in the feeder pillar and, being at ground-level, are readily accessible. Furthermore, it is inconvenient to install a transformer of a size greater than 50 kVA on a platform above ground-level. The arrangement proposed may be a little more expensive than a complete outdoor installation with bare leads, but the advantages arising from neatness and accessibility are worth the extra cost.

(4) 150- *to* 300-*kVA* (*and over*) *Substation.*—Substations of these sizes are best catered for by means of kiosks, as shown in Fig. 28. If the substation be inserted in a "section pole" position—and this will most likely be the case as it is best to sectionalize where there is the likelihood of a good load—a 2-way horn-break switch should be fitted to the top of the pole, the centre leads going to a cable box and thence by cable to the kiosk. Bare leads can be taken to pot-heads fitted to the top of the kiosk, but if this is done it will entail, for safety reasons, the erection of an unclimbable fence round the kiosk; hence the cable "lead-in" is the best. An oil-break switch fitted with an overload trip, or an oil fuse-switch, the latter being much the cheaper, may be installed in the kiosk. An oil switch with overload trip gear loses much of its usefulness if unattended, and as neither type of switch can receive constant attention both may be a source of trouble rather than a source of safety, especially the overload trip type. Hence an oil fuse-switch is the most useful and serviceable for this kind of work. The kiosk will contain isolating links and an l.t. fuse-rack suitable for the number of l.t. circuits that are required. One advantage of a kiosk over a brick-built substation is that it can be moved fairly easily if the load develops to such an extent as to require a larger installation.

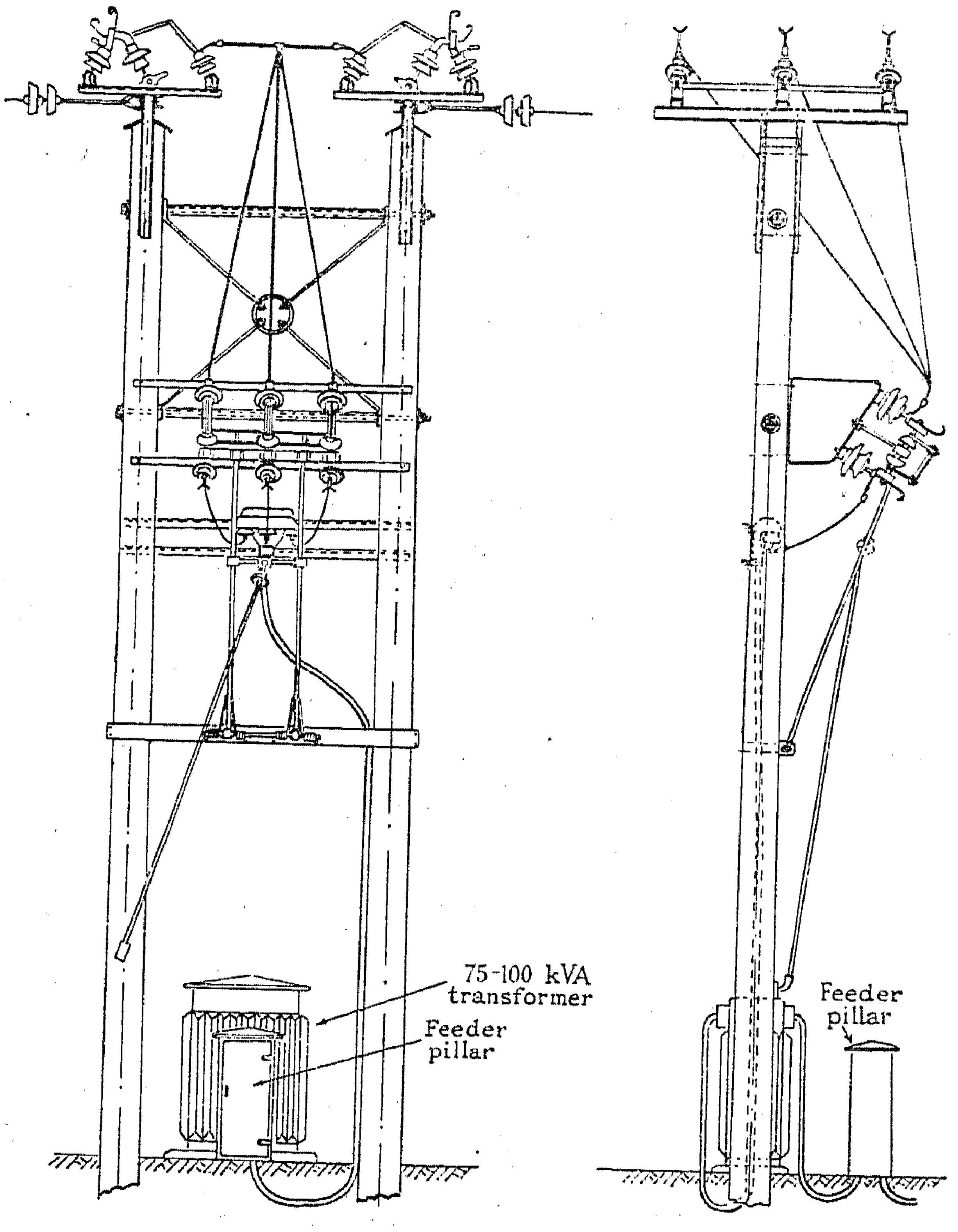


Fig. 27.—Transformer pole (75–100 kVA).

As an alternative to a horn-break switch on the pole, an oil-immersed change-over fuse-switch may be installed in the kiosk or alongside the transformer outside in the open. Such an arrangement requires two cable boxes placed back to back on the pole, with corresponding leads to afford the necessary means for the loop-in. There are several quite good arrangements of this type of equipment.

When a rural scheme is planned, the type of equipment most suitable generally for this size of substation and for the requirements of the scheme as a whole should be selected and standardized throughout in all details.

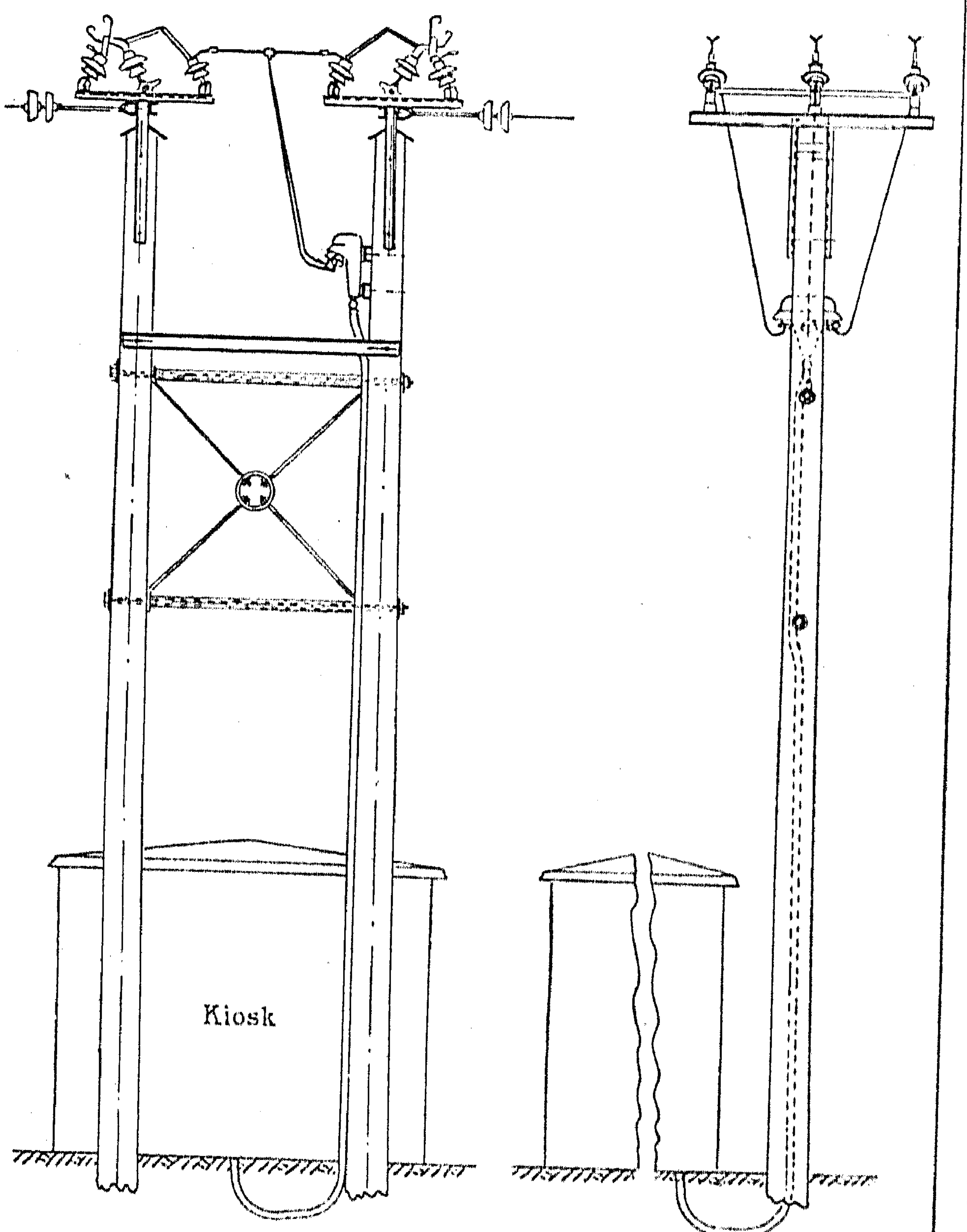


FIG. 28.—Transformer substation (150–300 kVA).

With regard to rural substation work generally, the authors have arrived at the following conclusions:—

(1) It is not economically possible to use any of the usual types of protective gear.

(2) Substations must be designed to eliminate constant attention.

(3) Fuses should be inserted between the line and transformer, on both the h.t. and the l.t. sides.

(4) When the transformer is in a kiosk, an oil fuse-switch should preferably be employed.

(5) When a transformer is erected on a pole, the h.t. fuse should preferably be of the type that can be pulled down to ground-level. This type of fuse-gear, however, is rather too expensive on the 5- to 15-kVA installations, and, for these sizes, as an alternative a link-fuse can be used in which the link can be unhooked and brought to ground-level by means of a pole.

(B) LOW-TENSION DISTRIBUTION.

(a) *Voltage and Choice of Conductor.*

Voltage.—This is determined by the Electricity Commissioners' Regulations for 3-phase circuits at 230 volts between neutral and line conductor, and 400 volts between conductors.

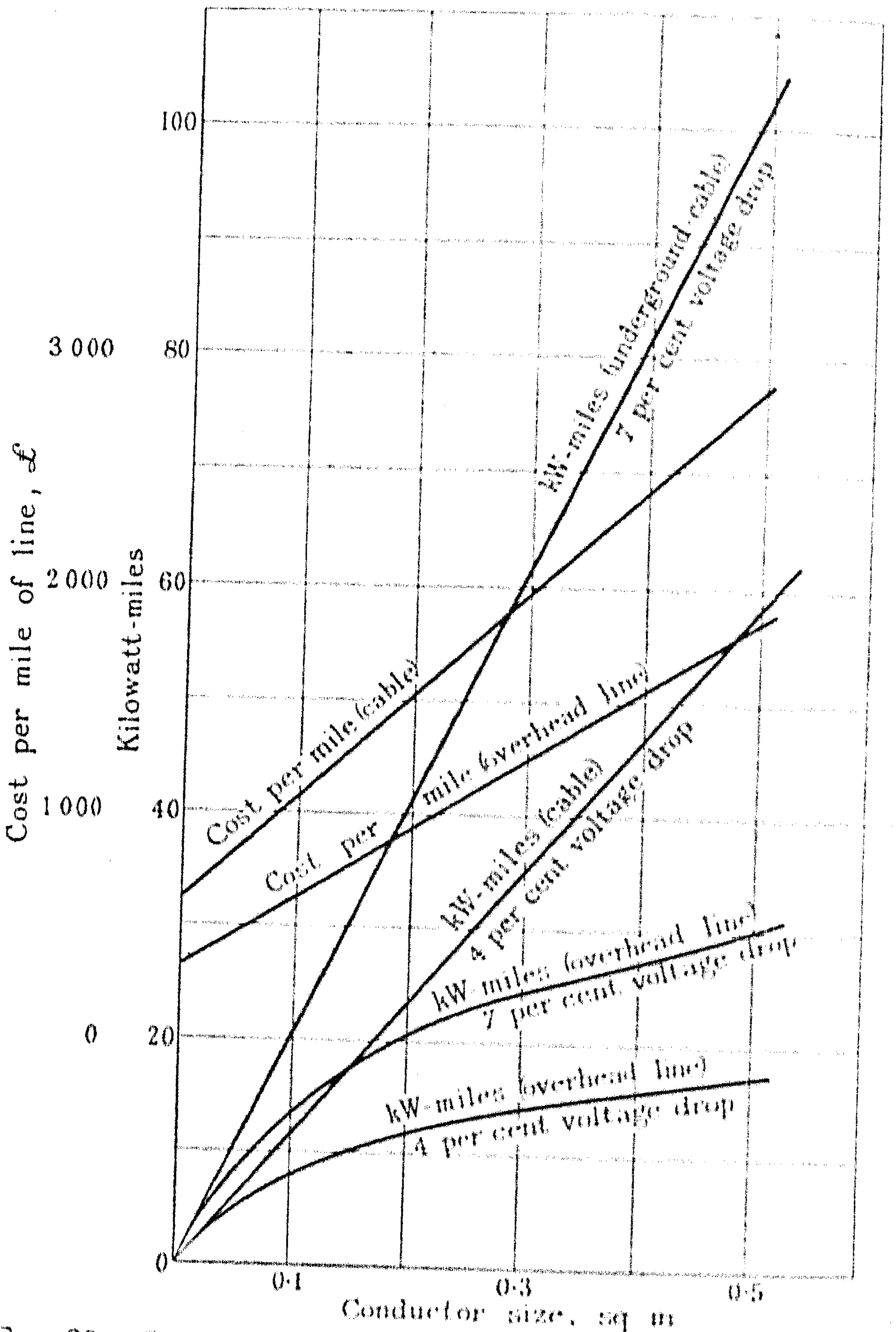


FIG. 29.—Curves showing relation between cost per mile and conductor size for 400/230-volt, 3-phase, 50-cycle, 4-wire lines. Power factor = 0·8.

Choice of Conductor.—The possibility from the point of view of economy of using l.t. underground distribution cable is a matter that should be considered. While in the case of h.t. transmission at 11 000 volts the idea of using underground cable has not been entertained, for l.t. 400/230-volt work cables may in certain instances be cheaper than overhead lines. Underground l.t. cable networks lack flexibility. With overhead lines an increased demand can be met by a change in the size and number of conductors, whereas in the case of an underground cable an immediate choice of size must be made adequate to deal with the estimated demand at the end of a number of years, thus involving unremunerative capital outlay in the earlier period. On the other hand, when comparing the conductor size of underground cable with that needed for overhead, it must be remembered that at a 0·8 power factor a 0·06-sq. in. 4-core cable gives approximately the same voltage-drop as a 0·1-sq. in. 4-wire overhead line. With improving power factor, the comparison in favour of underground cable is not so marked, until at 0·9 power factor little difference will be noted. Villages in which distribution by cable is cheaper than by overhead line are those in which dwellings are concentrated with usually a number of small streets, entailing many angles and junction poles. These angle-poles are not always convenient to stay, and sometimes self-supporting poles have to be installed. The question whether l.t. underground cables can be employed economically is governed also by other factors such as the prime cost of the cable, cost of excavation, laying the cable, and reinstating the road surface. Only when cable is obtainable at the lowest cost and excavation can be carried out at a cost of about 1s. 6d. per yard run, and reinstatement at 1s. per yard, does it appear feasible to justify the expenditure involved. Other points in favour of cable are that it is out of sight, that the undertaker is not called upon to obtain the consent of the Minister of Transport to the installation, and that wayleaves with the consequent delay are reduced to a minimum.

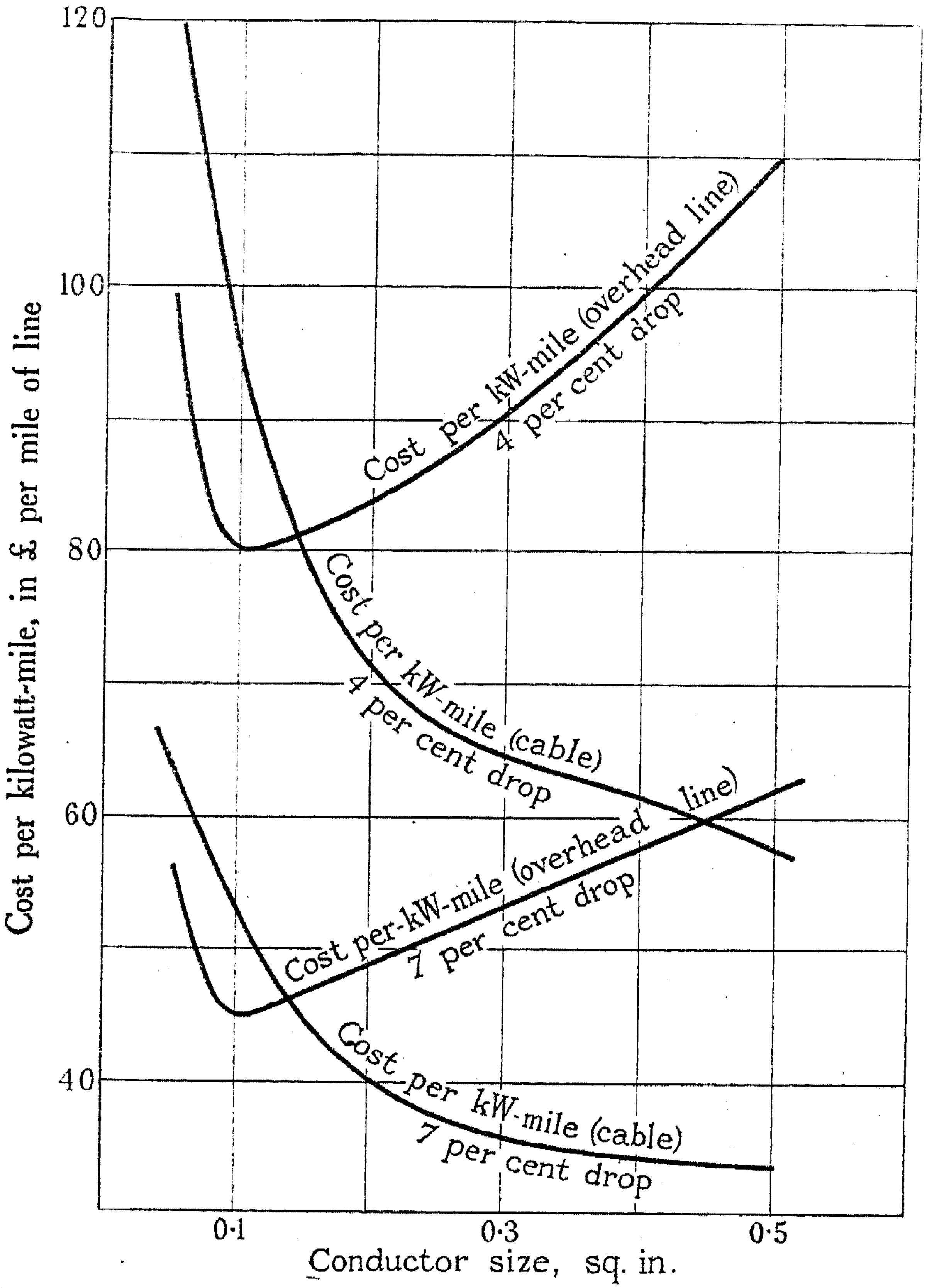


FIG. 30.—Curves showing relation between cost per kilowatt-mile per mile and conductor size for 400/230-volt, 3-phase, 50-cycle, 4-wire lines. Power factor = 0·8.

Figs. 29 and 30 are self-explanatory, and illustrate generally the economics of l.t. distribution. For rural work it is doubtful whether a conductor greater than 0·2 sq. in. is an economic proposition. At this point an additional substation is generally cheaper. In making general comparisons of this nature it must be remembered that every case will have its own particular economy, and that generalizations may be erroneous. The only useful purpose served by curves of this nature is that they can be a guide.

The curves are based respectively on a 4 per cent and 7 per cent voltage-drop on the line, but should, for example, a heavy cooking load be present in close proximity to the substation, the current density might easily be the limiting factor determining conductor size, and it is in such circumstances that cable may prove cheaper than an overhead line.

The curve showing cost per kilowatt-mile indicates that one gets more for one's money by using 0·1 sq. in. conductor, but this by no means indicates that this size of conductor is under all circumstances the best one to use. It does mean, however, that little is to be gained by using a larger size. Should the load call for a larger conductor, it would be advisable to explore other methods of transmitting the load, e.g. an additional feeder or an extra substation. It becomes a matter of weighing up and estimating the cost of other alternatives, keeping in mind future expansion. If the load does not warrant a 0·1-sq. in. overhead line, then it is obvious that the capital cost will be less if a smaller size be used. For anything over 0·15 sq. in. a cable is the cheaper, the cable costs being estimated on lead-covered paper-insulated cable laid direct in the ground. It would have been difficult and perhaps misleading to have included the cost of services in this chart, but when making comparisons these must be taken into account.

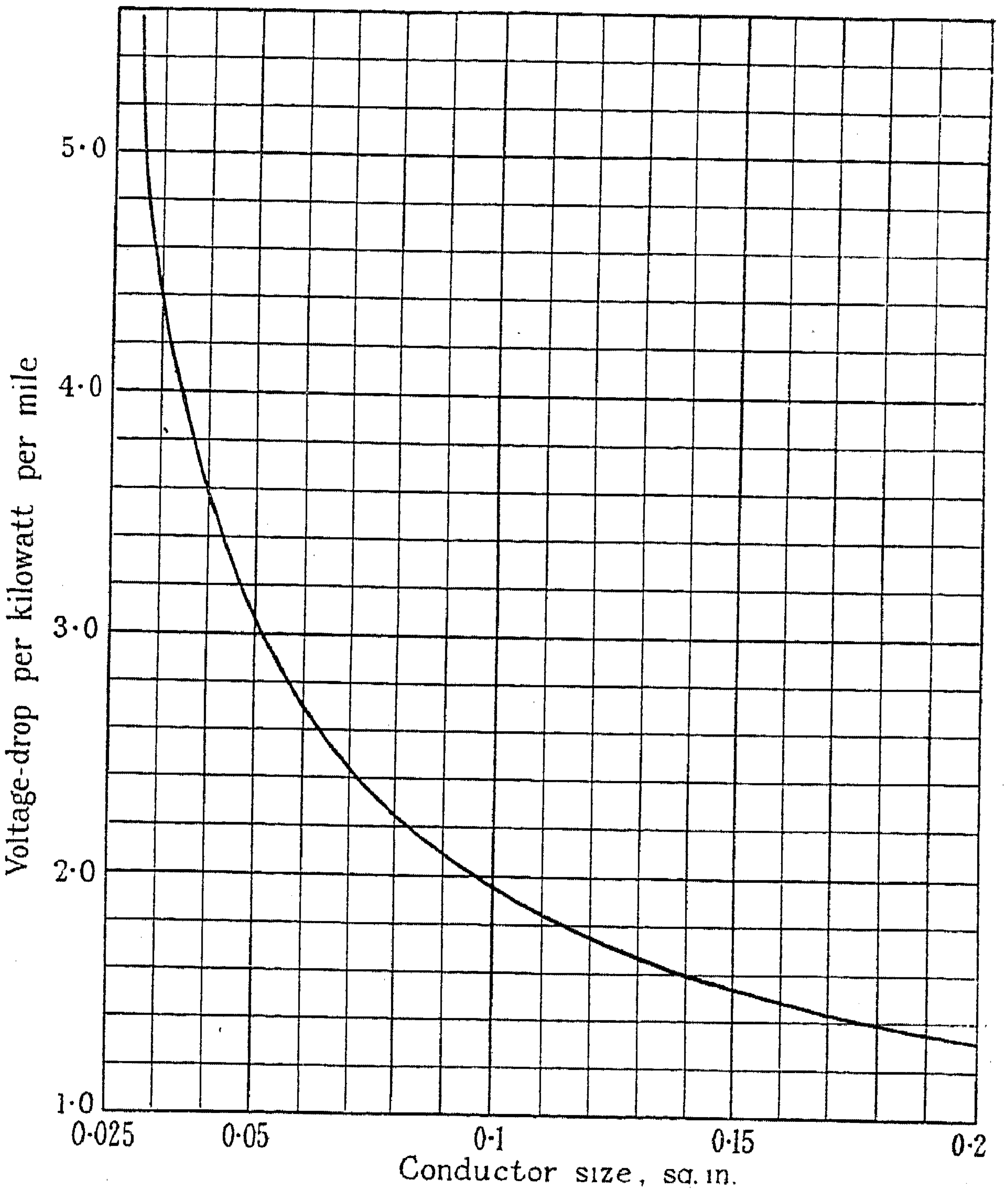
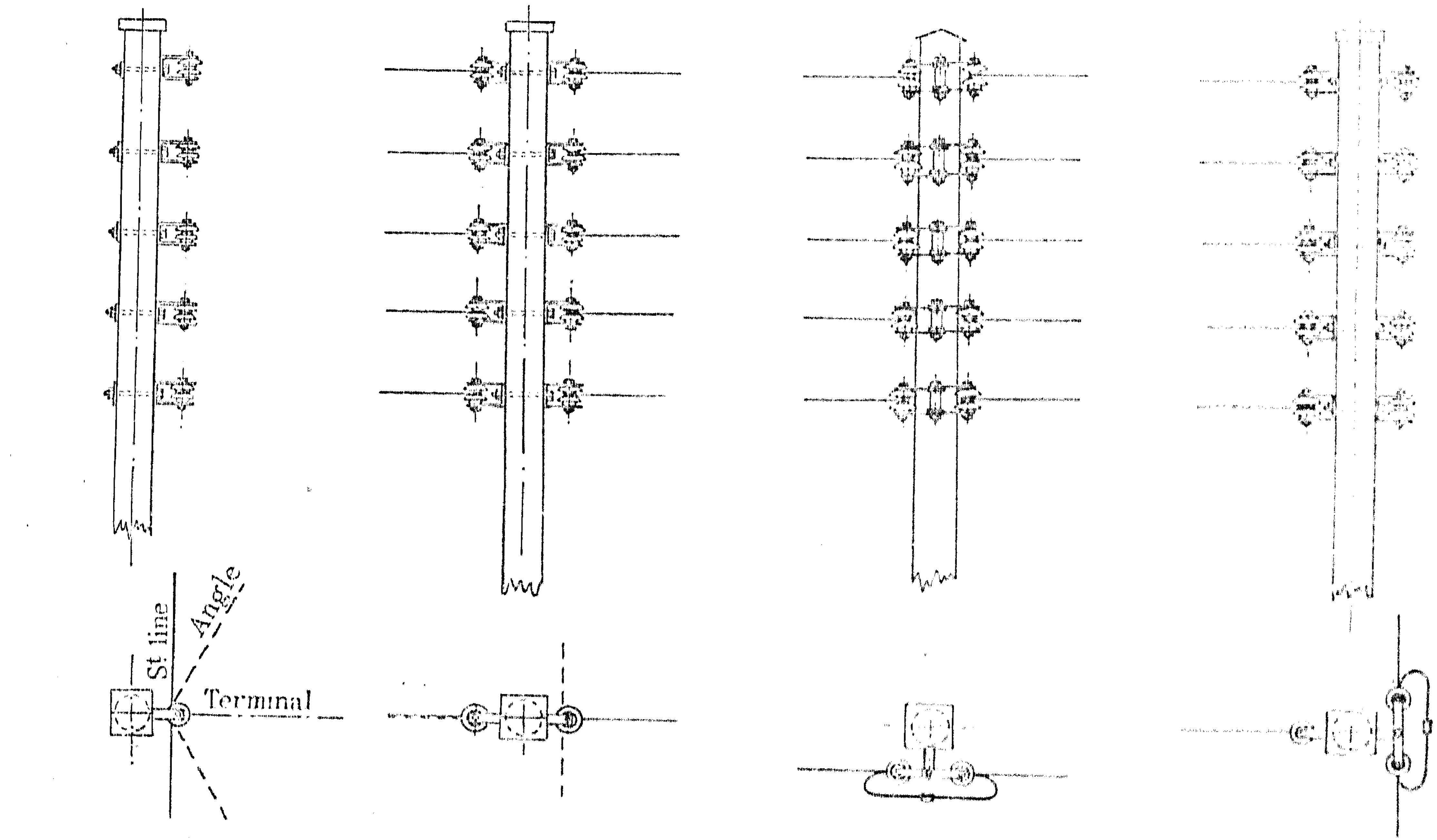


FIG. 31.—Curve showing relation between voltage-drop and conductor size.

On the whole the authors are convinced that the fullest possible use must be made of overhead lines for rural areas. They realize that amenities must be considered, but it appears quite possible to meet all reasonable criticism on this score if due care is taken in the selection of pole positions and in the arrangement of conductors.

The factor determining the sectional area of the conductor is almost always the permissible voltage-drop. As can be seen from Fig. 31, there is little to be gained by using a conductor greater than 0·1 sq. in. sectional area (expressed as copper or its equivalent), and only in extreme cases should a conductor of 0·15 sq. in. be adopted. The choice of conductor material is fairly simple, as there is little saving, if any, by using material of higher tensile strength than copper where, as in this case, spans are short. Moreover, copper has a higher scrap value than, say, steel-cored aluminium or aluminium alloys. The span is practically determined between 100 and 180 ft.; spans of 150 ft. have almost become a standard. Poles must always be placed in positions governed by the services to be given and, with long spans between poles, services become inconvenient and unsightly. The sag of the conductor on these small spans is insignificant, no matter what size of conductor or material is used. It is advantageous to cut down the maximum working tension as much as possible and thus relieve the loading on the angle and junction poles. For l.t. work, therefore, the authors are convinced that a copper conductor is the only one worth consideration at the present time.



Straight line, angle or terminal pole. Section or "tee" pole. Alternative section pole. Section "tee" pole.

FIG. 32.

(b) Lay-out of Distribution Lines.

It has been mentioned that there are roughly two types of village commonly met with in rural England, viz. (i) the cluster type and (ii) the ribbon type. Both types have their disadvantages when it comes to l.t. distribution.

(i) The cluster type of village is made of up short streets, resulting in many angles and odd pieces of line, while it is frequently difficult to stay the angle poles owing to lack of ground space. The houses are usually built close up to the road with little or no footpath, and overhead-line poles may sometimes be a menace to traffic. Usually one finds a Post Office pole already installed in the best spot!

(ii) In the ribbon type of village, usually of later development than the preceding, the houses as a rule have front gardens and there are footpaths. The length of l.t. mains required is, if anything, greater than for the cluster type; usually one finds the largest load at the furthest end of a ribbon village.

The substation should, of course, be placed as near as possible to the centre of gravity of the load. It will be found that each village presents its own problem.

Careful consideration should always be given to the lay-out of overhead distribution lines in a village. The overhead lines can be placed either along streets or behind the houses. The advantage of the first method is that no wayleaves are required, and the poles can be used for street lighting. In the second position, the line does not in any way destroy the amenities of the village. Preliminary trouble in preparing alternative schemes will be amply repaid. Much trouble has been caused owing to haphazard arrangement of lines.

(c) Construction of Overhead Lines.

Wooden poles are most generally used and are at present the cheapest form of support. Tubular steel poles are frequently used for main roads owing to what is considered to be their better appearance, but this is a matter of opinion. Normal-size, steel poles cost from 30s. to £3 apiece more than creosoted, red-fir poles, and it is doubtful whether their life is as long. Furthermore, steel poles do not lend themselves well to methods of pole-top attachment. Haulage is a difficulty that does not arise where the lines are erected along village streets.

As already indicated, it is inadvisable in the design of l.t. lines to string the conductor to the limit of the factor of safety of 2 permitted by the Electricity Commissioners' Regulations. It is best to fix upon a maximum sag of, say, 2 ft. on a span of 150 ft., at the assumed temperature of 122° F. (this sag is in excess of that calculated with a factor of safety of 2), and then to string up the conductors to such a tension that at this temperature the sag will be the same as the one thus arbitrarily fixed. When erecting l.t. conductors it is essential that the linesman should work to a chart of sag temperature and sag tension. As it is difficult to use a dynamometer on l.t. poles, the sag should be carefully measured; this can easily be done with the aid of a marked rod.

In the authors' opinion the best arrangement for the pole top is that shown in Fig. 32. This is now being widely adopted throughout the countryside. It is neat, strong, simple, cheap, and calls for only one type of insulator, one type of **D** iron, and a bolt. Services can be taken off in many different directions with the utmost simplicity. Shackle straps can be used at the section poles, thus making for convenience when stringing conductors. A step further has been taken with this type of construction, with a view to economy, by dispensing with the **D** iron on intermediate poles. The shackle insulator is fixed in a horizontal position by means of a coach screw or bolt. Some engineers are, however, averse to the use of coach screws on overhead-line work.

The appearance of this type of line is quite neat, and the position of the insulators facilitates the stringing of the conductors. There is no reason why l.t. overhead lines should look untidy. If the method of construction indicated is adopted and the conductors are erected as proposed, they present a neat appearance and are not so conspicuous as telephone wires. It is when the conductors are festooned, each span showing a different sag, and when the supports are out of plumb, that l.t. overhead lines are an eyesore.

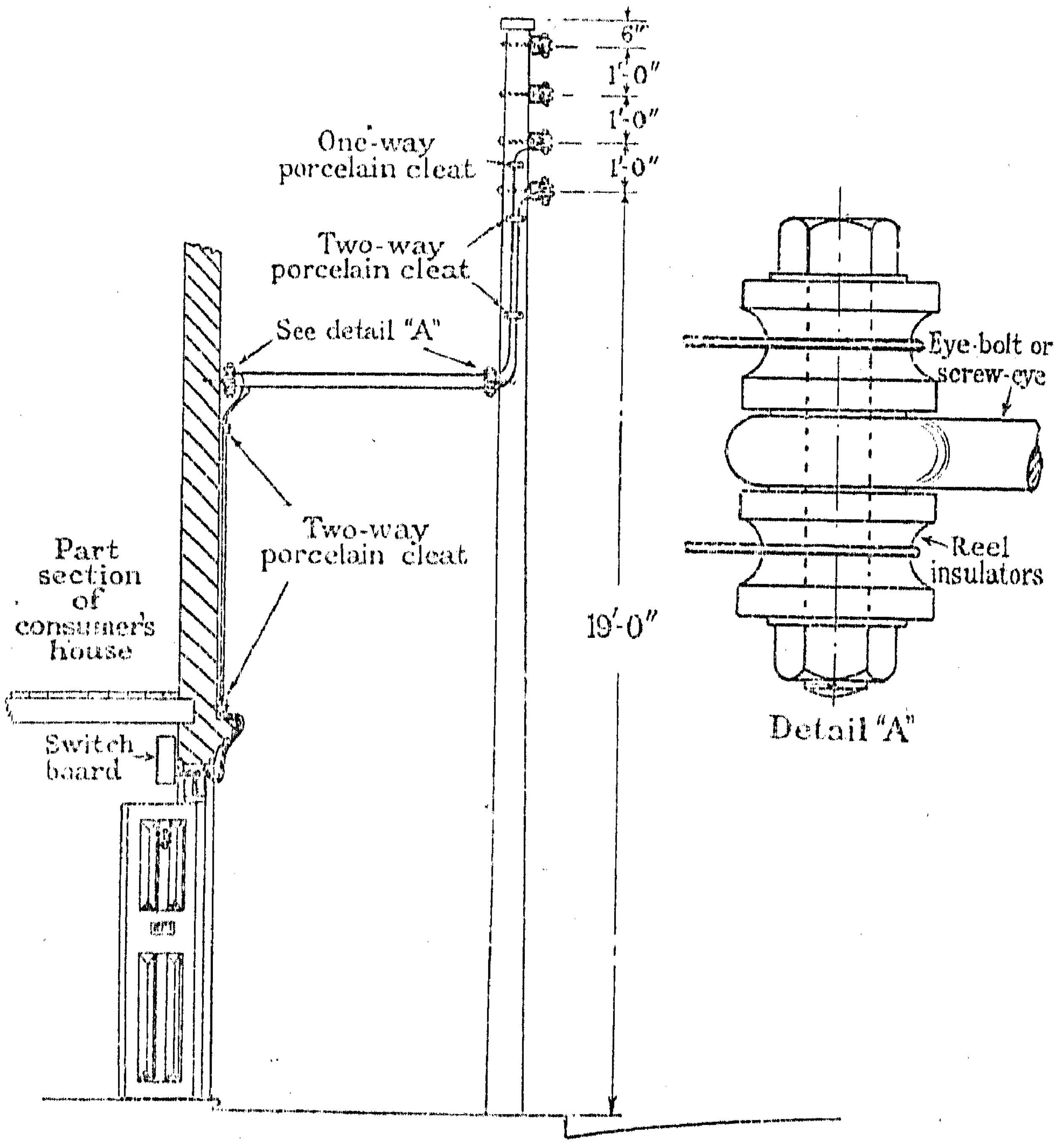
In France it is customary to support the l.t. lines by means of brackets fixed to the walls of the houses, and this method is frequently seen in suburbs and villages. This practice is influenced by the type of architecture and the narrow streets, nearly all the houses having three stories and being built flush on the pavement; the pavement is as a rule narrow. The British village with its variety of types of architecture and front gardens and fairly wide road does not lend itself to this treatment.

In the case of Council housing estates where the houses are fairly uniform, what may be called the "under the eaves" type of line has been developed. The conductors are insulated and braided with a material suitable for open-air use, and are cleated under the eaves of the houses. Should the distance between houses be great the conductors are supported by a light, steel catenary wire. The service is tapped and taken down the wall of the house (preferably the back), the lead-in being just over the back door. This makes a very neat and serviceable construction and is scarcely noticeable.

Brackets have been fixed to the chimneys of a row of bungalows, and the lines carried on these. Any departure from standard practice depends entirely on local conditions, and there is no reason why poles should be used if an efficient support is already there.

(*d*) *Services to Consumers.*

Services can be neat and tidy if they are properly strung. Under present practice they seem occasionally to get out of hand and can appear very ugly, especially when wires cross roads at varying heights. Several houses, if of the terrace type, can be connected conveniently through one service, the connecting conductors being run under the eaves. In the case of cottages and small houses it is sometimes best to take service wires down the pole by cleating, and then horizontally across to the consumer. Fig. 33 shows this arrangement, which has a workmanlike appearance.



Section transverse to line

FIG. 33.—Low-tension house-service lead-in.

Another type of service, inexpensive and not unsightly, is one in which the connection is made as usual at the pole top and carried down the pole a short distance just below the l.t. conductors and closely supported along a light, steel catenary wire strung between adjacent poles and then at the most convenient point carried across at right angles to the consumer's premises.

(*e*) *Organization of Erection.*

Much economy in the erection of overhead lines can be effected by good organization. No work should be commenced until all wayleaves are settled. The route should be carefully surveyed well in advance and a complete list of quantities prepared. The shortest route is almost invariably the best, and in these islands little or no gain can be effected by the erection of h.t. lines along public roads, because they are far from straight and there are usually Post Office lines to be avoided. Material should be bought in as large a quantity as possible, as this is an effective means of cheapening costs. As much work as possible should be done in the shop. Packing and bolting the material together should be carried out with a view to easing the work in the field. The erection of a single-pole line is a straightforward job. The use of heavy tractors and mass erection methods cannot always be applied with advantage, owing to the nature of the countryside. Heavy haulage and excavating machinery causes damage to hedges, fences, and crops, and the resultant compensation incurred may easily outweigh their apparent economy. The frequency of ditches and our uncertain climate are also impediments to their usefulness.

Care must be taken to avoid an undue amount of transport, as this can easily become a costly item, and the use of light poles of such a weight as can be man-handled across fields and over hedges is an important consideration.

Recapitulation.

Following upon the foregoing examination, it may be useful at this juncture to state briefly the more important features of the Model Scheme.

System of Supply.

Alternating, 3-phase, 50 cycles per second.

Voltage.

For h.t. main and spur lines: 11 000 volts.
For l.t. distribution lines: 400/230 volts, 3-phase.

Conductors.

For h.t. main overhead lines: steel-cored aluminium.
For h.t. spur lines: copper and steel.
For l.t. distribution lines: copper.

Supports.

Red-fir single poles throughout.

Spans.

For h.t. main transmission lines: 350 ft. (approx.).
For h.t. spur lines: 200 ft. (approx.).
For l.t. distribution lines: 100–180 ft., average 150 ft.

Road Crossings.

For h.t. main and spur lines: duplicate insulators with bridles, and earth bars.

Insulators.

For h.t. main and spur lines: pin insulators.
For l.t. lines: shackle insulators with D-iron top fittings.

Earthing Arrangements.

H.T. pole: earthed at each pole.
L.T. distribution systems: earthed at one point only, viz. the neutral point at substation end.

Pole Fittings.

For h.t. 3-phase lines: as shown in Fig. 21.
For h.t. spur lines: similar to Fig. 21.
For l.t. distribution lines: as shown in Fig. 32.

Transformers.

British Standard as to output, voltage, ratios, etc., oil-cooled.

Substations.

For outputs of 15 kVA: pole type; conductor directly connected to fuse; latter removable by hooked rod, and transformer fixed on pole.
For outputs of 15 to 50 kVA: pole type; direct-connected fuses removable by swing frame; transformer mounted on pole platform.
For outputs of 75 to 100 kVA: outdoor type; with h.t. and air-break switch on pole top; fuses supported on swing frame, and transformer at ground-level.
For outputs of 150 to 300 kVA: air-break switch on pole top; h.t. leads brought down to kiosk in which are placed h.t. oil fuse or overload trip switch; transformer and l.t. fuses and links.

L.T. Distribution Systems.

Overhead 3-phase copper conductor erected over footpath, margin of road, or through private property by consent, at front or back of houses. Where frontages are in line and buildings are close together, by attachment, by consent, to front or back of buildings.

Services.

Run at right angles to distribution line where latter fronts dwellings, as shown in Fig. 33. Otherwise down face of building where lines are attached thereto.

Organization.

Wayleaves obtained before work begins; material purchased in large quantities; assembly work of parts done in workshops; avoidance of repetition of gang movements over the erection course; care in transport and in placing of details along the course.

(12) COST OF MODEL SCHEME.

We can now apply our results to estimate the capital cost and revenue of the Model Scheme which, it will be remembered, is an area of about 400 square miles with a population density of 150 persons per square mile. It is assumed that of the area 4 per cent is urban, and this is excluded from the scheme, leaving a net area of 384 square miles and a population of 57 600 persons.

The following schedule gives the cost of the main items which go to make up, with the preliminary and incidental expenditure, the total cost of the scheme.

SCHEDULE OF COSTS.

H.T. Transmission.

11 000-volt, 3-phase, 50-cycle, overhead line, single circuit, 0·05 sq. in. (copper equivalent) steel-cored aluminium conductor on single wooden poles, normal span 350 ft., erected complete in 100–200 mile lengths or over, per mile £375

L.T. Distribution.

400/230-volt, 3-phase, 50-cycle, overhead line, 4 wires on wooden poles, normal span 150 ft., stayed at angle positions, Post Office crossings protected. For 0·1 sq. in. copper conductor erected complete, per mile £640

For 0·05 sq. in. copper conducted erected complete, per mile £500

For No. 8 S.W.G. copper conductor erected complete, per mile £425

Spur Lines.

11 000-volt, 3-phase, 50-cycle, overhead line, single circuit, copper conductors on single wooden poles, normal span 200 ft., erected complete. Alternatively galvanized steel at same cost, per mile £235

Substations.

As specified on pages 218, 219, and 220, excluding cost of the "H" pole—

(*a*)	5-kVA installation (see Fig. 25)	each	£47
(*b*)	15-kVA installation (see Fig. 25)	each	£52
(*c*)	25-kVA installation (see Fig. 26)	each	£76
(*d*)	50-kVA installation (see Fig. 26)	each	£92
(*e*)	75-kVA installation (see Fig. 27)	each	£212
(*f*)	100-kVA installation (see Fig. 27)	each	£225
(*g*)	200-kVA installation (see Fig. 28)	each	£410
(*h*)	300-kVA installation (see Fig. 28)	each	£475

House Services.

Overhead services, each £2

TABLE 26.

Village Equipment Cost.

(Density 150.)

Type of village	Population	Number of consumers	Size of overhead conductors	Cost of low-tension line	Cost of house services	Cost of transformer station	Total cost	Cost per head of population
				£	£	£	£	£
A	60	12	8 S.W.G.	121	24	52	197	3·28
B	210	43	8 S.W.G.	296	86	76	458	2·18
C	450	92	0·05 sq. in.	436	184	92	712	1·58
D	770	157	0·10 sq. in.	722	314	213	1 249	1·62
E	1 000	205	0·10 sq. in.	910	410	225	1 545	1·55
F	1 800	369	0·10 sq. in.	1 520	738	410	2 668	1·48
G	3 000	610	0·10 sq. in.	2 540	1 220	475	4 235	1·41

Village Equipment.

Table 26 gives at a glance the total cost of the electrical equipment, from the point of the h.t. supply as far as the consumers' premises, for the several sizes of villages A to G brought under review (see Table 21 on page 207).

With the aid of the figures in Table 26 the capital expenditure has been compiled, and this is presented in summarized form (see page 226). It will be seen that the capital expenditure amounts to £300 500.

The estimated rate of capital expenditure is shown, by means of Fig. 34, over a period of 7 years. It will be noted that the first 12 months is assumed to be devoted to the topographical and electrical survey, seeking Parliamentary powers, raising capital, obtaining wayleaves, and preparing plans and specifications (say, 5 per cent of total expenditure). The following two years are devoted to the general equipment of the scheme,

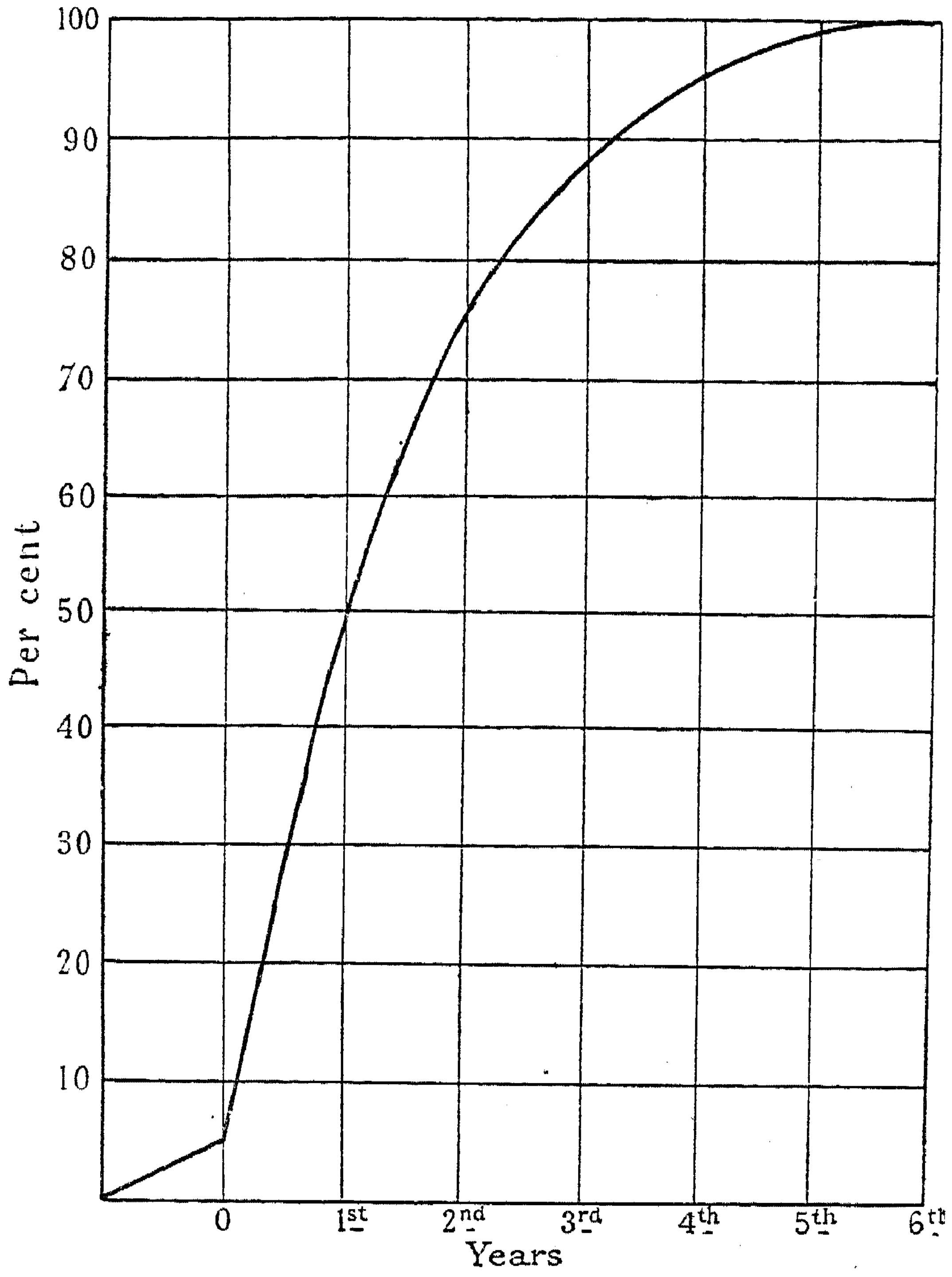


FIG. 34.—Estimated rate of capital expenditure.

STATEMENT OF CAPITAL EXPENDITURE.

400 Square Miles of Territory, or 384 Square Miles of Rural Area.
Density of Population per Square Mile—150.
Copper (electrolytic bars) taken at £55 per ton. Lead at £17.

Erected under contract	Unit cost	Total cost	Grand total
	£	£	£
Topographical and electrical survey. Seeking Parliamentary powers, raising capital, obtaining wayleaves, and preparing plans and specifications (say 5 per cent of total expenditure) ..	—	—	13 622
216 miles of 11 000-volt, 3-phase, single-circuit, 0·05 sq. in. (copper equivalent), steel-cored aluminium conductor, single wooden poles, normal span 350 ft., including crossings at two per mile, tree-lopping, and fence repairs	375	—	81 000
8 miles of 11 000-volt, 3-core, 0·06 sq. in., paper insulated, lead sheathed, steel taped and armoured cable for urban districts and/or crossing, including excavation, laying and jointing, and reinstatement	—	—	11 730
192 miles of spur lines, 11 000-volt, 3-phase, single-circuit, including crossings, for isolated load equipments	235	—	45 120

96 village equipments, including transformers and switches:—

Type of village	Transformer station and switchgear	Number of villages	Unit cost	Total cost	Grand total
	kVA				
A	15	16	52	832	
B	25	28	76	2 128	
C	50	24	92	2 208	
D	75	12	213	2 556	
E	100	4	225	900	
F	200	8	410	3 280	
G	300	4	475	1 900	
					13 804

Erected under contract	Unit cost	Total cost	Grand total
384 isolated equipments (averaging 5 kVA each). Farms, residences, institution, etc. ..	47	—	18 048
Equipment for industrial load on line of route of electrical mains, estimated at an average of 35 kVA per parish, 96 parishes. Total 3 360 kVA	2·75	—	9 240

Low-tension, overhead distribution lines and services in villages. Overhead lines, 3-phase, 4 conductors, wooden pole construction, 150-ft. spans with ample allowance for staying at angle positions and at Post Office crossings at costs given below:—

Type of village	Size of conductor	Length of low-tension lines in village	Number of villages	Total length of low-tension lines	Cost per mile	Unit cost	Total cost	Grand total
		yards		yards	£			
A	No. 8 S.W.G.	500	16	8 000	425	—	1 932	
B	No. 8 S.W.G.	1 227	28	34 356	425	—	8 297	
C	0·05 sq. in.	1 533	24	36 792	500	—	10 453	
D	0·10 sq. in.	1 983	12	23 796	640	—	8 652	
E	0·10 sq. in.	2 500	4	10 000	640	—	3 636	
F	0·10 sq. in.	4 200	8	33 600	640	—	12 220	
G	0·10 sq. in.	7 000	4	28 000	640	—	10 184	
								55 374

Erected under contract	Unit cost	Total cost	Grand total
Services—9 530	2	—	19 060
Meters—9 530 at average of £2 each	2	—	19 060
			286 058
Contingencies .. .. 5 per cent	—	—	14 303
Total estimated cost	—	—	£300 361
(Say £300 500)			

REVENUE AND EXPENDITURE ACCOUNT.

Model Scheme of 400 Square Miles of Territory.

Urban, 16 square miles; Rural, 384 square miles. Rural Population 57 600; Density 150 per square mile.

Capital expenditure	Preparatory year	1	2	3	4	5	6
	£	£	£	£	£	£	£
Capital expenditure during year	15 025	135 225	75 125	39 065	21 035	10 520	4 505
Total capital expenditure to date	15 025	150 250	225 375	264 440	285 475	295 995	300 500

REVENUE ACCOUNT

Year of working	Preparatory year	1	2	3	4	5	6
Units purchased (thousands) ..		1 044	3 851	7 569	11 449	15 810	19 638
Price per unit, d. ..		0·912	0·724	0·657	0·624	0·605	0·587
kW bought ..		953	2 586	4 431	6 224	8 201	9 746
Expenditure:—							
		£	£	£	£	£	£
I. Cost of electricity purchased	—	3 965	11 610	20 705	29 765	39 830	48 040
II. Distribution costs	—	825	1 880	3 060	3 435	3 635	3 730
III. Management expenses:—							
(*a*) General ..	—	1 550	2 085	2 865	3 410	3 695	4 215
(*b*) Publicity	—	2 050	1 850	1 545	1 325	1 040	520
IV. Rents, rates, and taxes	—	225	2 250	3 380	3 965	4 280	4 440
Total	—	8 615	19 675	31 555	41 900	52 480	60 945
V. Capital charges:—							
Interest, 4·75 per cent ..	—	3 925	8 920	11 635	13 060	13 810	14 170
Sinking fund, 3 per cent ..	—	2 480	5 635	7 350	8 250	8 720	8 950
VI. Interest on working capital ..	—	120	290	440	570	700	800
Total ..	—	15 140	34 520	50 980	63 780	75 710	84 865

Year of working	Preparatory year	1	2	3	4	5	6
Total units sold (thousands) ..		783	3 081	6 204	9 623	13 342	16 678
Price per unit sold, d.		4·24	2·66	2·03	1·70	1·51	1·38
Units sold per consumer		300	590	880	1 170	1 460	1 750
Revenue:—							
		£	£	£	£	£	£
Sale of electricity ..	—	13 847	34 150	52 470	68 170	83 960	95 900
Meter rents, 5 per cent of revenue ..	—	693	—	—	—	—	—
Meter rents, $2\frac{1}{2}$ per cent of revenue ..	—	—	855	—	—	—	—
Meter rents, nil ..	—	—	—	—	—	—	—
Total	—	14 540	35 005	52 470	68 170	83 960	95 900
Deficit	—	600	—	—	—	—	—
Surplus	—	—	485	1 490	4 390	8 250	11 035
Total	—	15 140	34 520	50 980	63 780	75 710	84 865

but during these years services are going on simultaneously; this work requires 70 per cent of the capital expenditure. During the last four years, devoted to extensions and services, 25 per cent of the capital is expended.

The revenue and expenditure, over a period of 6 years, is next considered. This again is conveniently presented in tabular form as a revenue and expenditure account.

For the more complete understanding of the above figures, table, and illustration, the following elucidatory notes are appended.

Elucidatory Notes.

With regard to the expenses on revenue account, the cost of electricity per unit delivered to the Model Scheme has been taken on the basis of a 2-part charge at £3·25 per kW plus 0·2d. per unit. This gives an average cost per unit of 0·912d. at the outset, decreasing thereafter to an average cost of 0·57d. per unit in the sixth year of operation. In the earlier years, substantial allowance has been made for canvassing and advertising expenses, but in the latter part of the period decreasing amounts have been provided. Provision has been made for distribution costs, management expenses, rents, rates, and taxes, as follows:—

(i) Distribution costs:—
  (*a*) Repairs, maintenance and renewals of system, and adequate service to consumers, taken at 1 per cent on the capital expenditure for the first two years, and 1¼ per cent for the following years.
  (*b*) Operating costs, salaries, and wages.

(ii) Management expenses—based on capital expenditure to end of year, and taken at from 5¾d. per £ in the first year, down to 3¾d. in the sixth year—include:—
  (*a*) Salaries and wages in respect of preliminary expenses, general management, accountancy, legal fees, auditing, clerical, and meter reading, and office accommodation, stationery, telephones, etc.
  (*b*) Publicity—includes salaries and wages of sales engineer and of staff employed in showroom operation and upkeep. Also special propaganda, e.g. travelling showroom. General insurances, not debitable to distribution.

(iii) Rents, rates, and taxes—includes wayleaves rentals, pole rentals at 1s. 3d. per pole, together with all rent, rates, and taxes, the total amount being computed at 1·5 per cent of the capital expenditure.

It will be observed that items (i) to (iii) represent about 4·0 per cent of the capital expenditure at the end of the sixth year.

With regard to the capital charges, it is expected that, with development on the substantial scale outlined and with the security afforded by the fact that it is a public service, investors will be satisfied to accept 4·75 per cent interest per annum. Depreciation has been based on the average life of the various portions of the equipment equated to 20 years of the whole, and payments to depreciation or sinking fund account have been taken at 3 per cent on the total expenditure, the rate of accumulation by interest of this fund being taken at 3·5 per cent per annum. Interest on working capital on the basis of 33⅓ per cent of the annual revenue for 6 months at 5 per cent interest.

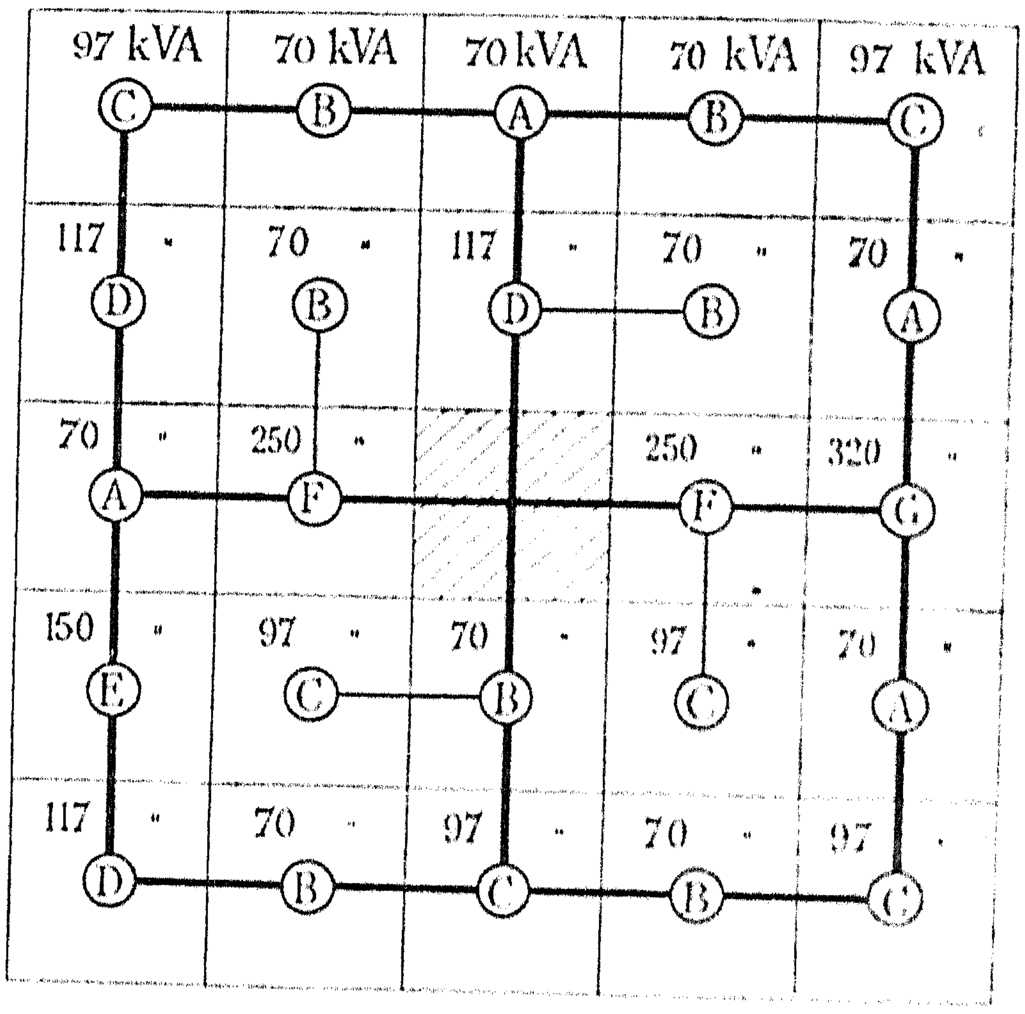


Fig. 35.—Area of 100 square miles with density of 100 per sq. mile.

0·05-sq. in. conductors.
steel or light copper line.

Income is calculated as shown in Section (8) above, and includes meter rents for the first year at 5 per cent of the gross revenue, and at 2½ per cent for the second year, entire omission being allowed for in the subsequent years. The authors are of opinion that the earliest possible opportunity should be taken to abolish meter rents.

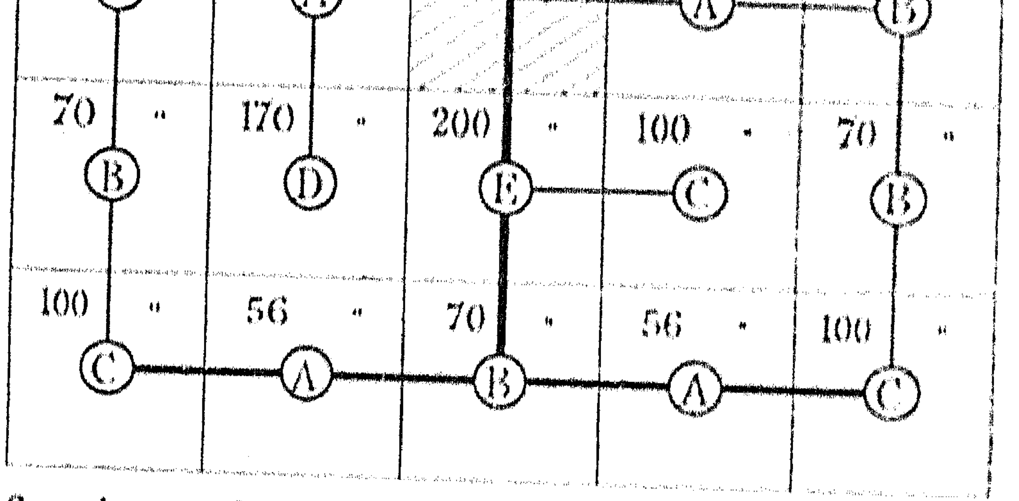


Fig. 36.—Area of 100 square miles with density of 75 per sq. mile.

0·05-sq. in. conductors.
steel or light copper line.

After providing for all interest and depreciation payments, the estimates show surpluses on each year's working after the first year. When these become sub-

TABLE 27.

Loading of No. 2 Scheme.

Density 100; Area 384 square miles; Premises 23 per square mile; Total number of Premises 8 832.

Year	Degree of saturation	Total number of consumers	Units sold per consumer			Total units sold per annum to consumers	Losses (on units sold)	Electricity bought at point of supply		
			Domestic	Power	Total			Units bought	Load factor	kW bought
	per cent					thousands	per cent	thousands	per cent	kW
1	20	1 766	200	100	300	530	$33\frac{1}{3}$	707	$12\frac{1}{2}$	646
2	40	3 532	360	230	590	2 084	25	2 605	17	1 750
3	54	4 768	520	360	880	4 195	22	5 118	$19\frac{1}{2}$	2 996
4	63	5 562	680	490	1 170	6 507	19	7 743	21	4 209
5	70	6 181	840	620	1 460	9 024	$18\frac{1}{2}$	10 693	22	5 548
6	73	6 446	1 000	750	1 750	11 280	$17\frac{3}{4}$	13 282	23	6 592

TABLE 28.

Loading Table of No. 3 Scheme.

Density 75; Area 384 square miles; Premises 17 per square mile; Total number of Premises 6 528.

Year	Degree of saturation	Total number of consumers	Units sold per consumer			Total units sold per annum to consumers	Losses (on units sold)	Electricity bought at point of supply		
			Domestic	Power	Total			Units bought	Load factor	kW bought
	per cent					thousands	per cent	thousands	per cent	kW
1	20	1 305	200	100	300	391	$33\frac{1}{3}$	522	$12\frac{1}{2}$	477
2	40	2 611	360	230	590	1 541	25	1 926	17	1 293
3	54	3 525	520	360	880	3 102	22	3 784	$19\frac{1}{2}$	2 215
4	63	4 112	680	490	1 170	4 810	19	5 724	21	3 112
5	70	4 570	840	620	1 460	6 671	$18\frac{1}{2}$	7 905	22	4 101
6	73	4 765	1 000	750	1 750	8 339	$17\frac{3}{4}$	9 819	23	4 873

STATEMENT OF CAPITAL EXPENDITURE.

400 Square Miles of Territory, or 384 Square Miles of Rural Area.
Density of Population per Square Mile—100.
Copper (electrolytic bars) taken at £55 per ton. Lead at £17.

Erected under contract	Unit cost	Total cost	Grand total
	£	£	£
Topographical and electrical survey. Seeking Parliamentary powers, raising capital, obtaining wayleaves, and preparing plans and specifications (say 5 per cent of total expenditure) ..	—	—	10 830
186 miles of 11 000-volt, 3-phase, single-circuit, 0·05 sq. in. (copper equivalent), steel-cored aluminium conductor, single wooden poles, normal span 350 ft., including crossings at two per mile, tree-lopping, and fence repairs	375	—	69 750
6 miles of 11 000-volt, 3-core, 0·06 sq. in., paper insulated, lead sheathed, steel taped and armoured cable for urban districts and/or crossings, including excavation, laying and jointing, and reinstatement	—	—	8 760
176 miles of spur lines, 11 000-volt, 3-phase, single-circuit, including crossings, for isolated load equipments	235	—	41 360

96 village equipments, including transformers and switches:—

Type of village	Transformer station and switchgear	Number of villages	Unit cost	Total cost	Grand total
	kVA				
A	15	16	52	832	
B	15	28	52	1 516	
C	35	24	80	1 920	
D	50	12	92	1 104	
E	75	4	213	852	
F	150	8	320	2 560	
G	200	4	410	1 640	
					10 424

Erected under contract	Unit cost	Total cost	Grand total
288 isolated equipments (averaging 5 kVA each). Farms, residences, institution, etc. ..	47	—	13 536
Equipment for industrial load on line of route of electrical mains, estimated at an average of 23 kVA per parish, 96 parishes. Total 2 208 kVA	2·75	—	6 072

Low-tension, overhead distribution lines and services in villages. Overhead lines, 3-phase, 4 conductors, wooden pole construction, 150-ft. spans with ample allowance for staying at angle positions and at Post Office crossings at costs given below:—

Type of village	Size of conductor	Length of low-tension lines in village	Number of villages	Total length of low-tension lines	Cost per mile	Unit cost	Total cost	Grand total
		yards		yards	£			
A	No. 8 S.W.G.	333	16	5 328	425	—	1 285	
B	No. 8 S.W.G.	1 033	28	28 924	425	—	6 985	
C	0·05 sq. in.	1 300	24	31 200	500	—	8 865	
D	0·05 sq. in.	1 583	12	18 996	500	—	5 395	
E	0·10 sq. in.	1 800	4	7 200	640	—	2 620	
F	0·10 sq. in.	3 000	8	24 000	640	—	8 730	
G	0·10 sq. in.	4 833	4	19 332	640	—	7 030	
								40 910

Erected under contract	Unit cost	Total cost	Grand total
Services—6 446	2	—	12 892
Meters—6 446 at average of £2 each	2	—	12 892
			227 426
Contingencies .. .. 5 per cent	—	—	11 372
Total estimated cost	—	—	£238 798
(Say £239 000)			

REVENUE AND EXPENDITURE ACCOUNT.

Scheme of 400 Square Miles of Territory.

Urban, 16 square miles; Rural, 384 square miles. Rural Population 38 400; Density 100 per square mile.

Capital expenditure	Preparatory year	1	2	3	4	5	6
	£	£	£	£	£	£	£
Capital expenditure during year	11 950	107 550	59 750	31 100	16 725	8 375	3 550
Total capital expenditure to date	11 950	119 500	179 250	210 350	227 075	235 450	239 000

REVENUE ACCOUNT.

Year of working	Preparatory year	1	2	3	4	5	6
Units purchased (thousands) ..		707	2 605	5 118	7 743	10 693	13 282
Price per unit, d. ..		0·912	0·724	0·657	0·624	0·605	0·587
kW bought ..		646	1 750	2 996	4 209	55 48	6 592
Expenditure:—							
I. Cost of electricity purchased	—	£ 2 685	£ 7 860	£ 14 010	£ 20 135	£ 26 960	£ 32 490
II. Distribution costs	—	660	1 495	2 435	2 735	2 890	2 965
III. Management expenses:—							
(*a*) General ..	—	1 230	1 660	2 280	2 710	2 935	3 350
(*b*) Publicity	—	1 635	1 470	1 225	1 055	830	415
IV. Rents, rates, and taxes	—	180	1 800	2 690	3 155	3 405	3 530
Total	—	6 390	14 285	22 640	29 790	37 020	42 750
V. Capital charges:—							
Interest, 4·75 per cent ..	—	3 125	7 100	9 250	10 390	10 985	11 270
Sinking fund, 3 per cent ..	—	1 970	4 480	5 845	6 560	6 940	7 115
VI. Interest on working capital ..	—	80	200	310	395	485	540
Total ..	—	11 565	26 065	38 045	47 135	55 430	61 675

Year of working	Preparatory year	1	2	3	4	5	6
Total units sold (thousands) ..		530	2 084	4 195	6 507	9 024	11 280
Price per unit sold, d.		4·24	2·66	2·03	1·70	1·51	1·38
Units sold per consumer		300	590	880	1 170	1 460	1 750
Revenue:—							
Sale of electricity ..	—	£ 9 360	£ 23 100	£ 35 490	£ 46 090	£ 56 780	£ 64 870
Meter rents, 5 per cent of revenue ..	—	470	1 160	1 780	—	—	—
Meter rents, 2½ per cent of revenue ..	—	—	—	—	1 150	1 420	—
Meter rents, nil ..	—	—	—	—	—	—	—
Total	—	9 830	24 260	37.270	47 240	58 200	64 870
Deficit	—	1 735	1 805	775	—	—	—
Surplus	—	—	—	—	105	2 770	3 195
Total	—	11 565	26 065	38 045	47 135	55 430	61 675

STATEMENT OF CAPITAL EXPENDITURE.

400 Square Miles of Territory, or 384 Square Miles of Rural Area.
Density of Population per Square Mile—75.
Copper (electrolytic bars) taken at £55 per ton. Lead at £17.

Erected under contract	Unit cost	Total cost	Grand total
	£	£	£
Topographical and electrical survey. Seeking Parliamentary powers, raising capital, obtaining wayleaves, and preparing plans and specifications (say 5 per cent of total expenditure) ..	—	—	8 520
92 miles of 11 000-volt, 3-phase, single-circuit, 0·05 sq. in. (copper equivalent), steel-cored aluminium conductor, single wooden poles, normal span 350 ft., including crossings at two per mile, tree-lopping, and fence repairs	375	—	34 500
4 miles of 11 000-volt, 3-core, 0·06 sq. in., paper insulated, lead sheathed, steel taped and armoured cable for urban districts and/or crossing, including excavation, laying and jointing, and reinstatement	—	—	5 915
234 miles of spur lines, 11 000-volt, 3-phase, single-circuit, including crossings, for isolated load equipments	235	—	54 990

96 village equipments, including transformers and switches:—

Type of village	Transformer station and switchgear	Number of villages	Unit cost	Total cost	Grand total
	kVA				
A	15	28	52	1 456	
B	25	36	76	2 736	
C	50	20	92	1 840	
D	100	8	225	1 800	
E	125	4	250	1 000	
					8 832

Erected under contract	Unit cost	Total cost	Grand total
192 isolated equipments (averaging 5 kVA each). Farms, residences, institution, etc.	47	—	9 024
Equipment for industrial load on line of route of electrical mains, estimated at an average of 17 kVA per parish, 96 parishes. Total 1 632 kVA	2·75	—	4 488

Low-tension, overhead distribution lines and services in villages. Overhead lines, 3-phase, 4 conductors, wooden pole construction, 150-ft. spans with ample allowance for staying at angle positions and at Post Office crossings at costs given below:—

Type of village	Size of conductor	Length of low-tension lines in village	Number of villages	Total length of low-tension lines	Cost per mile	Unit cost	Total cost	Grand total
		yards		yards	£			
A	No. 8 S.W.G.	500	28	14 000	425	—	3 375	
B	No. 8 S.W.G.	1 493	36	53 748	425	—	12 975	
C	0·05 sq. in.	1 517	20	30 340	500	—	8 620	
D	0·05 sq. in.	2 040	8	16 320	500	—	4 636	
E	0·10 sq. in.	2 750	4	11 000	640	—	4 000	
								33 606

Erected under contract	Unit cost	Total cost	Grand total
Services—4 765	2	—	9 530
Meters—4 765 at average of £2 each	2	—	9 530
			178 935
Contingencies .. .. 5 per cent	—	—	8 945
Total estimated cost	—	—	£187 880
(Say £188 000)			

REVENUE AND EXPENDITURE ACCOUNT.

SCHEME OF 400 SQUARE MILES OF TERRITORY.

Urban, 16 square miles; Rural, 384 square miles. Rural Population 28 800; Density 75 per square mile.

Capital expenditure	Preparatory year	1	2	3	4	5	6
	£	£	£	£	£	£	£
Capital expenditure during year	9 400	84 600	47 000	24 450	13 150	6 600	2 800
Total capital expenditure to date	9 400	94 000	141 000	165 450	178 600	185 200	188 000

REVENUE ACCOUNT.

Year of working	Preparatory year	1	2	3	4	5	6
Units purchased (thousands) ..		522	1 926	3 784	5 724	7 905	9 819
Price per unit, d. ..		0·912	0·724	0·657	0·624	0·605	0·587
kW bought ..		477	1 293	2 215	3 112	4 101	4 873
EXPENDITURE;—		£	£	£	£	£	£
I. Cost of electricity purchased	—	1 985	5 810	10 350	14 890	19 930	24 020
II. Distribution costs	—	520	1 175	1 915	2 150	2 275	2 335
III. Management expenses:—							
(*a*) General ..	—	970	1 305	1 795	2 135	2 310	2 640
(*b*) Publicity	—	1 280	1 155	965	830	655	325
IV. Rents, rates, and taxes	—	140	1 400	2 115	2 480	2 680	2 780
Total	—	4 895	10 845	17 140	22 485	27 850	32 100
V Capital charges:—							
Interest, 4·75 per cent ..	—	2 455	5 580	7 280	8 170	8 640	8 865
Sinking fund, 3 per cent ..	—	1 550	3 525	4 595	5 160	5 455	5 600
VI. Interest on working capital ..	—	60	150	230	290	360	400
Total ..	—	8 960	20 100	29 245	36 105	42 305	46 965

Year of working	Preparatory year	1	2	3	4	5	6
Total units sold (thousands) ..		391	1 541	3 102	4 810	6 671	8 339
Price per unit sold, d.		4·24	2·66	2·03	1·70	1·51	1·38
Units sold per consumer		300	590	880	1 170	1 460	1 750
REVENUE :—		£	£	£	£	£	£
Sale of electricity ..	—	6 910	17 080	26 240	34 070	41 970	47 950
Meter rents, 5 per cent of revenue ..	—	345	850	1 310	—	—	—
Meter rents, 2½ per cent of revenue ..	—	—	—	—	850	1 050	—
Meter rents nil ..	—	—	—	—	—	—	—
Total	—	7 255	17 930	27 550	34 920	43 020	47 950
Deficit	—	1 705	2 170	1 695	1 185	—	—
Surplus	—	—	—	—	—	715	985
Total	—	8 960	20 100	29 245	36 105	42 305	46 965

stantial, and deficits in previous years are liquidated, a point is reached when, in the authors' opinion, consideration should be given to reduction of tariffs.

RÉSUMÉ OF THE PRINCIPAL FEATURES OF THE THREE SCHEMES.

Items (6th year of operation)	Scheme		
	Model (density 150)	No. 2 (density 100)	No. 3 (density 75)
Area, square miles ..	384	384	384
Inhabited houses ..	13 056	8 832	6 528
Number of consumers	9 530	6 446	4 765
Bulk supply, kW ..	9 746	6 592	4 873
Bulk supply, thousands of units	19 638	13 282	9 819
Total units sold to consumers, thousands ..	16 678	11 280	8 339
Total revenue on sale of current, £	95 900	64 870	47 950
Total revenue per unit sold, pence	1·38	1·38	1·38
Total revenue per consumer, £	10·06	10·06	10·06
Total costs, £	84 865	61 675	46 965
Total costs per unit sold, pence ..	**1·22**	**1·31**	**1·34**
Capital expenditure, £	300 500	239 000	188 000
Capital expenditure per square mile, £ ..	782·6	622·5	489·7
Capital expenditure per consumer, £ ..	**31·53**	**37·08**	**39·46**
Units sold per £ of capital	**55**	**47**	**44**
Capital per 1 000 units sold, £	**18·02**	**21·19**	**22·55**
Capital charges:—			
Interest at 4·75 per cent, £	14 170	11 270	8 865
Sinking fund at 3 per cent, £	8 950	7 115	5 600
Interest on working capital £	800	540	400
Capital charges per unit sold, pence ..	**0·344**	**0·403**	**0·428**
Total annual expenses, other than cost of bulk supplies, £ ..	36 825	29 185	22 945
Total annual expenses per unit sold, pence	**0·530**	**0·621**	**0·660**
Load factor on bulk supplies, per cent ..	23	23	23
Units sold per consumer	1 750	1 750	1 750
Revenue balance on year of account, £ ..	11 035	3 195	985

Estimates of capital expenditure, revenue, working expenses, and charges, are based upon prices and rates ruling in the spring of 1931. The authors believe that results from operation in subsequent years will not affect their conclusion that rural electrification can be carried out on an economic basis.

(13) SIMILAR SCHEMES BUT FOR LESS DENSITIES OF POPULATION.

It appeared to the authors worth while to work out schemes for the same area, but with less densities of population, to show the nature of the limits to which it may be possible to go under less favourable circumstances than those which have been assumed for the Model Scheme. Consequently, schemes for densities of population of (2) 100 persons per square mile, and (3) 75 persons per square mile have been compiled. In each case is presented:—

(*a*) A loading table on the lines of that in Section (9).
(*b*) A diagram of village interconnection modified to suit the lower loading (see Figs. 35 and 36).
(*c*) An estimate of the capital expenditure at the end of the sixth year. It will be noted that this amounts to £239 000 in the case of scheme (2) and to £188 000 in the case of scheme (3).
(*d*) An estimate of expenditure and revenue for the sixth year.

It will be observed that these tables and diagrams are compiled on lines exactly comparable with those of the Model Scheme.

In conclusion it may be useful to bring together the principal features of the three schemes. This conspectus is given in the adjoining column.

(14) CONCLUSIONS.

The following are the conclusions which the authors draw from their consideration of the design of a distribution system in a rural area.

(1) Rural areas in Great Britain over which distribution powers are held ("occupied areas") are about 48 000 square miles in extent, with an average density of 162 persons per square mile.

(2) In England and Wales only there are about 38 000 square miles of such areas, with an average density of 176 persons per square mile. Of this 38 000 square miles there are about 8 000 square miles or 21·5 per cent (reckoned by parishes) in which electricity is available; such areas have densities of about 375 persons per square mile.

(3) In the remaining 30 000 square miles in England and Wales over which distribution powers have been obtained, but in which electricity is not yet available, there is an average density of 123 persons per square mile. Within this area there are extensive areas of such average densities of population as to offer good prospect of electrification.

(4) The average revenue actually obtained for all purposes during 1928–29 from consumers connected to the mains of all authorized undertakings in Great Britain was £15·7; of this, 43 per cent was revenue from power.

(5) The average revenue for all purposes actually obtained during 1929–30 from consumers connected to the mains of 221 authorized undertakers from operations in rural areas was £12 per consumer; 50 per cent of this

was revenue from factories and large consumers. The revenue estimated under the Model Scheme ranges over a period of six years from £5·31 per consumer in the first year, to £10·06 in the sixth year.

(6) The wholehearted co-operation of authorized undertakers with manufacturers and contractors and with the Central Electricity Board is essential for the solution of the problem of rural electrification.

(7) With a product of unvarying quality as is electricity, and with a wide market such as is presented in rural areas, any reduction in the charge per unit to consumers will lead eventually to increased sales and greater revenue.

(8) By the courageous application of a tariff under which the charge for electricity is reduced *pro rata* to consumption, it can confidently be hoped to tap large sources of revenue.

(9) In the design of equipment for a scheme of rural electrification, designers should look well ahead of present requirements, and equipment should be projected for the area as a whole. This is recommended in preference to the sporadic development now largely adopted. The least area that should be considered is 400 square miles, but greater areas are desirable.

(10) The best pressure for h.t. distribution in rural work with scattered loading is 11 000 volts.

(11) The cost of overhead lines and equipment can be reduced to a minimum by standardization, bulk purchase of material, and such preparations as will ensure continuity of construction.

(12) No adequate reasons are apparent why electrification should not, in areas over which powers of supply are held and are not yet electrified, be proceeded with at once.

(13) With goodwill and co-operation, electrification can proceed on a sound financial basis, even in areas having average densities of population little above 75 per square mile.

The authors find it difficult to make personal acknowledgments, but they wish to express their obligation to those who have made this investigation possible by placing information at their disposal and in giving direct help and useful suggestions.

Discussion before The Institution, 19th November, 1931.

Mr. J. M. Kennedy: I should like to call attention to Tables 1 and 3, because the facts shown there appear to illustrate the difficulties which confront us. The last column in Table 1 shows that the capital expenditure on distribution represents an increasing percentage of the total capital expenditure on electricity supply, and there is no doubt that—owing to the spreading-out of supply systems into larger areas and the restricted amount of generation which will take place under the Central Electricity Board's scheme—this percentage must inevitably increase. Table 3 discloses the disturbing fact that the number of units sold per £ of capital is tending to fall; whereas this figure reached a maximum of 55 in the years 1923–24 and 1924–25, it is now down to only 50. The crux of the whole question is that we must make better use of the capital invested in distribution; otherwise we shall never be able to sell electricity cheaply. (Mr. Kennedy here exhibited a number of lantern slides.) Figures of the number of units sold per £ of distribution capital for practically all the undertakings in Great Britain, as compared with the average revenue of each per unit, show that those undertakers who are only selling about 20 units per £ of capital are all selling at comparatively high cost. Only when one reaches an average figure of 50 units, such as is shown in Table 3, does one get down to a reasonable cost such as 1¾d. per unit; 1d. per unit is only achieved when a very large number of units are sold per £ of distribution capital. By combining the total costs of supply with the figure of actual distribution costs, to show the relation between distribution and total costs, one finds that at the lower number of units sold per £ of distribution capital the distribution costs are between 40 and 55 per cent of the total costs. This indicates that it is very important to increase the number of units sold per £ of distribution costs. The authors refer to the basis of units sold per consumer and revenue per consumer; while I agree that this basis is a useful one, the question of whether the undertaker is supplying a reasonable percentage of the total consumers in his area must also be taken into consideration. The relation between the number of units sold per consumer for all undertakings in Great Britain and the total distribution expenses shows that, by increasing the number of units sold, one may reduce the figure for distribution expenses to as low as 1d. At 1 000 units per consumer the corresponding figure is 1·3d., and at 500 units it is well above 2d. There are also a large number of smaller undertakings where the cost of distribution alone amounts to 3d., 4d., or even more, per unit. It is interesting to examine the curve showing the relationship between the number of units sold per head of population, which has been the criterion very often used, and the units sold per consumer. The shape of the curve is similar to that of Fig. 10, indicating that the basis the authors have chosen —units sold per consumer—is quite a good criterion, and it seems to imply that in general the undertaker who is selling a large number of units per head is also selling to a large proportion of his potential consumers. I should like to emphasize the authors' remarks about tariffs, because increased sales cannot be achieved unless proper tariffs and publicity methods are adopted. Each of the curves shown on this slide represents the results of one undertaking over a period of 8 years. The undertaking referred to in the top curve began in 1922, when it was selling electricity at an average price of 6·7d. per unit. This figure was reduced year by year and the undertaking is now selling at an average price of 2·7d. Due to these decreases in the tariff, the units sold per head of population increased from some 37 to 145. What is probably the record increase in sales occurred in the case of an undertaking which supplies a certain residential area. I have here the figures for six undertakings, in pairs of reasonable comparability. For each of the first pair the capital is almost the same, being over £600 000, but the gross surplus on the year's working is higher for the first undertaking than for the second. The average revenue per unit sold is 1·1d. in the first case, and 1·92d. in the second. The units sold per £ of distribution capital, however, are 121 in one case, as against 31 in the other. Whereas the load factors are practically identical, the units sold per consumer are 5 110 and 1 886 respectively. There is no reason why the latter undertaking should not get results very much more nearly equal to those obtained by the former, if the right methods are adopted. While I am in general agreement with the authors' figures and proposals, I think that their figures in connection with transmission lines are rather conservative. The contract price offered to us by an enterprising contractor for a 33 000-volt overhead line is only £414 per mile. The line passes over a piece of country which is divided up into small fields, so that the pole-foundation digging machine and poles frequently have to be carted through gaps in hedges, etc. The machine, which is levelled up by means of a spirit-level placed on its base, is carried on two big wheels with a swivelling control in front, and is pulled by one or two horses. A twin-cylinder petrol engine drives a horizontal shaft, which turns a vertical drill through bevel gearing; a special arrangement is adopted for removing stones from the cutting edge of the revolving tool. The drill is lowered 12 or 18 in. into the ground and is then pulled out by means of a lever; next, the engine is speeded-up, and earth and other excavated material is thrown out to one side and spread over the surrounding ground. The machine has been very successful in that it enables a hole to be bored in a few minutes, and it is very seldom that serious trouble due to stones or rocks is encountered. With regard to low-tension distribution, the authors suggest that in order to preserve the amenities of villages the lines should in some places be erected behind the houses. In practice, however, a forest of aerials is usually found behind the houses, and it is therefore impossible to act on this suggestion. This raises the question of the relative costs of pole and under-eaves distribution, to which I should like to refer. We are at present working on a contract figure of £433 per mile of distribution line having four 0·10-sq. in. conductors and all details in accordance with the Electricity Commissioners' Regulations. I do not think that the cable contractors can compete with this figure, although I have heard £650 per mile talked of. Unless, therefore, we can get a cheaper class of cable, overhead lines are the more economical proposition. With under-eaves construction instead of poles we get an outlay of £410 instead of £557 for two 0·10 sq. in., and we can get £351 instead of £509 for two 0·058 sq. in., but with four heavy conductors under-eaves construction costs more than poles. I should like to ask the opinion of the authors and of other speakers on the advisability of using a bare earth-wire if under-eaves construction is adopted. Personally, I can see no objection to it. Alternatively one might use P.B.J. covered cable and a bare earth-wire supported on porcelain cleats. The authors have not carried the subject to its logical conclusion. There appear to be some 41 000 square miles in this country which so far have not been provided with a supply of electricity. If the electrification of such areas is effected on the lines suggested by the authors, there seems to be no reason why it should not yield a profit. The capital expenditure involved in the scheme would be some 33 millions sterling, added to which there would be the capital expenditure on the consumers' wiring, cookers, etc., amounting to about 60 millions in the country generally. Thus practically 100 million pounds' worth of profitable work is waiting to be done to-day. This would provide 5 years' work for something like 140 000 men. The consumers are waiting, the unemployed are waiting, and the factories are not fully occupied; why should we not make a start with some, if not all, of this work? It seems to me that here is a real chance to undertake work which would be beneficial to the nation as a whole and also entirely self-supporting. In 6 years' time it would involve the consumption of an additional million tons of coal in the generating stations; it would bring into beneficial use some 800 000 kW of plant, and, further, it would reduce by at least 8 millions sterling the value of our imports of paraffin. Large-scale developments on the lines recommended by the authors are fully justified in the national interest, and I make an earnest plea for the widest possible co-operation between all concerned in connection with such schemes as are put forward, even though they may seem prejudicial to their local interests.

Mr. W. Fennell: I do not agree with the authors on the subject of independent earthing of poles. Great caution should be exercised in this connection, because in many parts of the country one cannot get a good earth-connection underground; the turf does not form a good earth, and the earth-plate is often put in sand, which has an insulating effect. The authors do not seem to approve of a very long pole spacing, but I think they have overlooked the great advantage of this, particularly for high-voltage distribution, due to the fact that it avoids the necessity of placing poles in the centres of fields. A good deal of trouble is avoided if the poles are all placed in hedges, and considerable wayleave rentals can be eliminated if this is done. With regard to low-voltage distribution, a too close spacing of poles tends to spoil the appearance of a village. The frequency with which the lines have to be tapped does not control the spacing to anything like the extent which it is generally thought to do. The tapping can be taken from a pole and then two or three consumers can be served from chimney to chimney. This enables the poles to be spaced wide apart, thus reducing cost and improving appearance. I should like to know how the authors' figure of £2 per service is estimated, as this seems to be an optimistically low value. In connection with transformer ratings, the authors suggest that a 25 per cent overload is allowable in most of the sizes. From temperature tests which I have taken it would appear that 50 and often 100 per cent overload are easily obtainable without the temperature of the transformer approaching within many degrees of that laid down in the British Standard Specification. The regulation of the transformer, and not the loading, is at present the limiting factor in these small sizes. The authors seem to assume that the rural population is spread uniformly over each section, i.e. they consider only the number of inhabitants per square mile. In rural areas, however, the inhabitants are distributed over each mile of road; thus, after the 33 000-volt lay-outs have been dealt with, the problem is a linear rather than a two-dimensional one. Great attention should be given to the details of the 11 000-volt lay-out, especially to the individual requirements of villages and development along roads. No reference is made in the paper to single-phase high-voltage distribution. Some important rural electrification schemes in this country are being carried out on that basis, and I should like to know the authors' opinion of it. I think that they have made a mistake in suggesting the introduction of tariffs based on a discount on quantity. If a consumer has to use 1 500 units per annum before the running charge is reduced from 4½d. (the normal price) to 1d. per unit, he will not install a single cooker and will take very little current for heating. This is a fatal objection to the authors' proposal. The authors state that a 2- or 3-h.p. motor is required to blow the bellows of a blacksmith's forge; a machine of this size would, of course, work many blacksmiths' forges, so that they may have over-estimated the number of units necessary to satisfy the power requirements of rural areas. The psychological portion of the paper requires strict scrutiny on the part both of the reader and of the authors.

Mr. F. M. Long: I am a little disappointed that the authors do not tell us exactly how they are going to get their revenue. While there is general agreement on the adoption of a fixed charge and a running charge, I agree with Mr. Fennell that it would be difficult to make that running charge vary much according to the quantity of energy consumed. In dealing with rural problems one has often to consider a supply to a consumer's premises which are some distance away from the existing mains. A large outlay is necessary, and it is difficult to know what terms one should ask from such consumers. The basis on which I now calculate the charge in such cases is as follows. The tariff consists of a fixed charge and a running charge of 1d. per unit. On a 30 per cent load factor, 1d. per unit is sufficient to cover the cost of current, which at grid prices is 0·6d. to 0·7d. per unit and leaves 0·3d. to 0·4d. to cover management and other expenses. It is satisfactory, therefore, if the fixed charge is sufficient to cover capital charges on the transmission and distribution costs. My own experience confirms the authors' figures of the cost of 11 000-volt lines and of local distribution, which for a large area are about equal to one another. Taking the capital charges at 7½ to 8 per cent, a return of 15 to 16 per cent on the local expenditure alone will be sufficient to cover both the local and the transmission costs. It is a useful rule that if a return in the form of fixed charges of 15 to 16 per cent on the special local expenditure is obtained in addition to the 1d. per unit, the costs of supply will be covered. In special cases one may even accept less than this, because connecting an extra consumer does not necessarily involve any extra expense on the main transmission lines, and if the outlay on these is already covered one need only consider the special expenditure involved. If, therefore, there are places where the full 15 or 16 per cent cannot be obtained, one must be content with about 10 per cent. I find it much better to charge consumers a definite amount per annum which will be sufficient to cover all the expenses, rather than to ask for a minimum annual guarantee. The consumers do not like minimum guarantees, and if their consumption does not reach the figure in question they say that they are being unfairly treated. If, on the other hand, a definite amount is charged, and then an unlimited supply of current is given at 1d. per unit, distribution in rural areas becomes a fairly simple matter. Our experience in the Norwich area is that after 3 or 4 years we are getting a sufficient return to cover the outlay and all the expenses. With regard to Table 12, do these figures represent the return which may be expected in country districts? The average given—of £19 8s. for 7 644 units—works out at only 0·61d. a unit. I do not see how such a figure could be made to cover all supplies in the country districts.

Mr. E. T. Norris: Mr. Kennedy has stressed the great importance of reducing the capital cost of transmission and distribution lines, the largest item in the total capital outlay. It is clear from the paper that the authors are convinced that voltage-drop is a very large item in the size, and therefore the cost, of transmission and distribution lines. Hitherto the only practical way of reducing that voltage-drop has been to increase the size of the conductor far beyond the values required by heating limits or losses. No other practicable solution of the problem occurs to the average supply engineer when planning a distribution system. As an illustration of the cost of obtaining satisfactory voltage regulation in this manner, it can be shown from the curves and figures given in the paper that for an average size of substation, involving a 75-kVA transformer, the extra cost of low-voltage distribution which is determined entirely by voltage regulation is £365. That £365 is spent on a rigid solution which cannot be adjusted if the actual loading conditions should prove to be greatly different from those foreseen by the engineer. Of recent years many manufacturers have been developing means of automatic voltage regulation by varying the tappings on transformers, or in other ways. It is only a few years since means of changing tappings on load were developed for very large transformers. When first introduced it was thought by most people that they would be of use only where conditions were particularly bad, e.g. in complicated problems involving interconnected stations; but at the present time, after the lapse of only a few years, this method has become practically universal for large transformers. To-day almost 95 per cent of the transformers of 3 000 or 4 000 kVA and over are fitted with this device. Many manufacturers have of late been intensively working on the development of similar gear for very small transformers. Such equipment has to be automatic, but automatic gear is to-day very well developed and standardized. The advantage of a variable-voltage transformer is not confined to the fact that it is a very much cheaper method of voltage regulation than the rather crude one of putting extra copper in a cable or transmission line. To give one example, I have already mentioned that in a typical case £365 of extra capital is suggested by the authors purely for obtaining suitable voltage regulation. Automatic variable-voltage transformers of the required capacity can be obtained for one-third of this amount. This solution of the problem is not only cheaper but also more flexible. Variable-voltage transformers can be standardized and made interchangeable, and they can be moved about as the load varies and the voltage-drop in one part of a system becomes of more importance than that in other parts. From this point of view they are unequalled, because no one would claim that transmission lines and cables are readily transportable! Another advantage is that regulation difficulties can be cured quickly by installing variable-voltage transformers. It is very much easier to install a variable-voltage transformer than it is to run another transmission line, even if provision has been made for running two lines over one set of poles. It is my firm belief that in a few years' time the ordinary static transformer, as we know it to-day, will be to the automatic variable-voltage transformer as the silent film is to the "talkie."

Mr. J. H. C. Brooking: The success of a distribution system sometimes depends on whether or not birds have been causing trouble on the overhead lines. This class of trouble usually cannot be foreseen, and therefore it is generally dealt with after a shut-down, when the feathered culprits are found electrocuted at the foot of the poles; bird guards are then adopted. This trouble is fairly general, but is not talked about as much as it should be, except possibly in correspondence. It is particularly prevalent in India, where mongoose and flying-fox abound, and where vultures and kites often carry the entrails of their prey to the cross-arms of the poles and there devour them. This problem is briefly referred to on page 215, but no mention is made of the Pernax bird guard which has been in operation since 1924. This device not only covers the live wire at the top of the insulator but also protects the former for 2 or 3 ft. on each side, and so saves a considerable amount of leakage on the system itself. Apart from acting as a bird guard, it has prevented salt storms from shutting down lines during bad weather. At the top of page 214 the authors state: "If the lines are near the sea or subject to winds coming from the sea, it is advisable to select an insulator rated higher than 11 000 volts." Though a larger insulator gives a longer path for surface leakage, it also gives a greater area of deposit to conduct the current over the insulator. The Pernax type of bird guard is now being developed to deal with cases where there has been trouble owing to the insulators being covered with conductive deposit. This guard not only shrouds the line on either side—and can be continued for any desired distance, thus enormously increasing the length of the conductive path—but it can also shroud entirely the porcelain insulator, its surface being less conductive than that of porcelain under similar severe atmospheric conditions. Pernax guards can be readily moulded so as to cover not only pole lines but also conductors on outdoor substations, where birds frequently cause as much trouble as they do on pole lines. Large numbers of these protective devices have, in fact, been used on the grid system.

Mr. J. N. R. Perks: The first thought that struck me on reading this paper was that we had disposed once and for all of the fallacy that a gross revenue of 20 per cent on the capital expenditure is necessary to justify an extension. In my view, that figure of 20 per cent is a relic of bygone days. It appeared in the Electricity Lighting (Clauses) Act of 1899, when electricity was sold for lighting purposes only, probably at an average of 6d. per unit. I think it is obvious that so far as extensions in rural areas are concerned the percentage return depends entirely upon the average price received. If a high average price is obtained, a revenue of 15 per cent may be quite sufficient; if, on the other hand, a load is being supplied at, say, 1d. per unit, the undertaker may require a revenue of 30, 40, or even 50 per cent to justify the capital expenditure. The authors are not entirely blameless in this respect, because on page 216 they assume that an undertaker should be satisfied with a rural extension giving a return of 20 per cent. I think that the sooner we get that figure out of our minds the better, and I hope that further legislation will clear up this very misleading point. My second thought on reading the paper was one of pleasure and relief that the amount of time spent by supply engineers every year in filling up forms for the Electricity Commission had been put to such good use. One item of information which we furnish regularly to the Commissioners has not, however, been used; I refer to the rateable value of premises in our areas of supply. I agree with the authors that the basis of the revenue per consumer is the best one to take in preparing estimates, though for a general survey the "units per head" basis may perhaps suffice. The revenue per consumer is, however, dependent on the ability of that consumer to purchase electricity, a factor which varies considerably from area to area. In the area within a radius of 2 miles of Bedford, or any other large town, the standard of living is considerably higher than in isolated rural districts, and the ability to purchase electricity is considerably greater than, say, in a depressed arable district such as East Anglia or in the mountainous districts of Wales. It is therefore desirable to arrive at some figure of wealth and relate it to the revenue per consumer. In America the consumption of commodities is sometimes related to the income tax payable in a given district. Although we are denied access to these figures, we have the figures of rateable value, and some time ago I tried to ascertain whether there was any relation between the revenue per consumer (or the units sold) and the rateable value. Unfortunately the De-Rating Act and the revised assessments under the quinquennial valuation made this difficult, but I should like to ask the authors whether they could ascertain if there is any relation between rateable value and revenue. The authors refer to a saturation revenue of £25 for farms, a figure which I regard as unduly pessimistic. Last week I saw the figures for 12 months' working of an ordinary arable farm in East Anglia, and I noticed that it was taking nearly 6 000 units per annum at an average price of 2½d., which represents a revenue of approximately £60. We have one or two other farms in the same district with like demands, and I think that loads of this type are only limited by the ability of farmers under the prevailing agricultural depression to purchase motors, and by the ability of authorized undertakers to extend their systems to these isolated consumers. I think that a figure of £50 represents quite a reasonable saturation point. The figures I have of the results of 3 or 4 years' working in rural areas hardly come up to those given in Table 11, possibly due to the fact that the latter deals with an area in the vicinity of a large town where the standard of living is higher. The first line in Table 12 gives an average price received of 0·56d. per unit, whereas the cost of bulk supply alone (including losses) would amount to 0·7d. per unit at a load factor of 23 per cent, and even with a load factor of 30 per cent the bulk-supply cost is 0·59d., so that although the figures in this table are of interest to urban districts, they cannot be applicable to rural areas. The figures in Table 12 will cause undertakers in urban districts to wonder what will happen to their profits when they purchase bulk supplies from the Central Electricity Board, and to ask themselves whether they are not selling energy for domestic purposes at rather too low a price having regard to the cost of bulk supply, capital charges on the distribution system, and management and distribution charges incurred in supplying the domestic load. Are they equally willing to supply small power consumers at a flat rate of ½d. per unit delivered at low tension? I think that every supply engineer ought to have a copy of the price/demand curve shown in Fig. 9 in front of him, and that he should base his estimates entirely upon it, because it shows the drooping average price with increased unit consumption. The authors state that the gross revenue per consumer increases with the unit consumption per consumer, and they give a curve (Fig. 9) showing the increase of revenue (which means, of course, gross revenue). (Mr. Perks here exhibited a lantern slide.) The top curve in this slide is the authors' curve of gross revenue. The curves of bulk-supply costs and rates, etc., are also shown, and I have included (by way of mild protest) the charges made by the Central Electricity Board for change of frequency. The summation of these costs deducted from the gross revenue gives the curve shown as " gross profit." (I call it " profit," but it really represents the balance available for capital charges, etc.) The profit curve is not far from being horizontal. If capital charges are taken into consideration, it would seem that such charges increase at a greater rate than the gross profit, showing a diminished return on capital for increased consumption. The diminution is very small, and if one is prepared to spend further capital for a slightly diminishing return, well and good; but it is difficult for local authorities or private enterprise to convince ratepayers or financiers respectively of the attractiveness of the proposition. With regard to the figures of capital expenditure, have the authors allowed sufficient for the cost of wayleaves? In my view these represent a considerable item in the cost of construction. I had an account from the Central Board recently for the cost of obtaining wayleaves for a pole line we were building on their behalf. They assured us that the bare cost of obtaining wayleaves amounted to 30s. per pole, or £25 per mile. In addition there are charges for compensation to tenants, tree-lopping, and other items, amounting to about another £25 a mile, so that we have to meet expenses of £50 per mile before we start construction. This is rather a large figure, and any legislation which will assist us in getting wayleaves will be welcome. I cannot think that the authors, in considering this scheme, have taken into account lengthy negotiations with such bodies as the Ecclesiastical Commissioners, the Forestry Commissioners, and the big railway companies, who, after months of negotiation, present a bill of costs—including the expenses of solicitors, surveyors, and other officials—amounting altogether to a very considerable sum. If we had more facilities for obtaining wayleaves our overhead lines would be cheaper. I do not think that the authors' allowance of 1½ per cent on the capital expenditure for rents, rates, and taxes (including wayleaves), is sufficient, as the corresponding figure on our systems for rates alone is approximately 6 per cent of the gross revenue. Again, wayleaves at 1s. 3d. are too low, for the awards of the Ministry of Transport are from 4s. in arable land down to 1s. in hedges. A figure of 2s. would probably be nearer the true average. While I believe in the possibilities of rural distribution, I think that these problems can best be solved by putting existing construction to the best possible use and keeping capital charges down, rather than by efforts to obtain any and every possible load regardless of the additional capital charges involved in strengthening distributors. I suggest that we should develop every small power load that we can get. Such loads can be obtained at a good average price, and they occur during the day-time. I advocate the development of the water-heating load, because it involves no appreciable additional capital charge. The use of small domestic appliances should be encouraged, as these are in use during the day and will not involve further capital charges. Refrigeration is an item which, although rather overlooked, helps considerably to smooth out the annual load curve. The occupants of almost every large or medium-sized house should be persuaded to put in a refrigerator, which has a yearly consumption of 300 to 400 units. This load yields a good average return and comes on mainly in the summer time.

Captain F. Risch: Of all types of consumers in this country, the rural consumer is the most difficult of approach. He has to be dealt with in a totally different way from other consumers. The authors are suggesting how the " peasantry " can be given a supply of electricity at a very low price and in the face of great handicaps in getting the supply to them. The closer the link between the Central Electricity Board and the consumer, from the commercial as distinct from the electrical point of view, the better for the rural electricity supply schemes. The load of isolated consumers is often uncertain, but they—particularly the farms—have to be reached, and at times at considerable cost to the farmer. The tariffs which have been in use for so long seem to penalize the lighting consumer. There may have been a reason for it in the old days of small stations and plant which ran for only a few hours at a time, but with plant running continuously this reason does not hold good. I should therefore like to see some of these rural houses wired and plug points placed in every room free of charge. Then, when electric light has been used for a few weeks, let the supply undertaking send a representative to demonstrate to the housewife the wonderful advantages of the electric iron and other domestic electrical appliances. Consumers of this class, who probably do not have fires at all during the summer time, are potential users of electricity for heating, and I therefore advocate encouraging them in every possible way to use electricity for heating and cooking, giving them the lighting units free. This is not a very drastic innovation, in view of the nature of the rural consumer. At the most, his lighting load is very small, even for the winter months. In the summer it falls off entirely, most rural cottagers retiring to rest before dark (summer time). This points to the necessity of encouraging this class of consumer to use electricity for purposes other than lighting. Therefore the cottage should be wired so that heating apparatus can be used in every room. On no account should the consumer be restricted as regards the consumption of electricity. Much money has been spent in reaching the rural consumer; it is well worth while to spend a little more in making his wiring installation worthy of its possible achievements.

(The discussion was then adjourned to the 26th November, 1931.)

ADJOURNED DISCUSSION BEFORE THE INSTITUTION, 26TH NOVEMBER, 1931.

Mr. R. W. L. Phillips: The data the authors have obtained represent average conditions over the whole of rural England, and care must be taken in applying them in any particular circumstances because the dwellers in different parts of rural England have widely varying habits. What the ploughman does in Essex, for instance, is quite different from what the ploughman does in Cornwall or in the North. One must be careful not to make the mistake of criticizing the paper from the point of view only of one's own experience in a particular area. In our district we are carrying out a special experimental scheme, of which I propose to give a few particulars. Before dealing with the Bedford scheme, however, I should like to touch on a few general points. Table 3 shows the diminution of revenue per £ of capital, which a previous speaker has rightly described as a very serious matter. If the revenue per £ of capital does not increase, one cannot obtain further capital, and without further capital the system cannot develop; development is a necessity if anything like saturation is to be obtained in the district of supply. I think, however, that this diminution is largely due to the fact that all our supply undertakings are at present developing at a very rapid rate. We are not falling into the old error of putting down cables to meet present requirements only. We are looking ahead and spending capital largely in advance of our revenue. Moreover, the fact that in the last 2 years the revenue per £ of capital has remained stationary indicates that there is no cause for alarm in this direction. With regard to Fig. 3, I have compared the figures given for the revenue per consumer with those for a typical small village in our district. The total number of consumers in this village who take their supply on a 2-part tariff is 38, and 5 of these have net rateable values above £20 per annum; the average rateable value for the remainder is £9. For the 33 consumers who have rateable values under £20, the majority of whom live in small cottages, the average number of units used per consumer is 1 245, costing £7 3s. 7d. per annum. The average rateable value of the whole village is £12 8s. 0d. per consumer, and the average consumption per consumer is 1 512 units, costing £9 0s. 10d. This development has been achieved without an assisted wiring scheme. With regard to hire-purchase, we have discovered an interesting trait in the country consumer around this district, inasmuch as, having been persuaded to purchase by instalments a piece of apparatus, he finally decides—when asked to sign the necessary documents—to pay cash. He calls it being "honest." We anticipate a similar experience on the introduction of assisted wiring. On page 201 the authors remark on the dissimilarity between

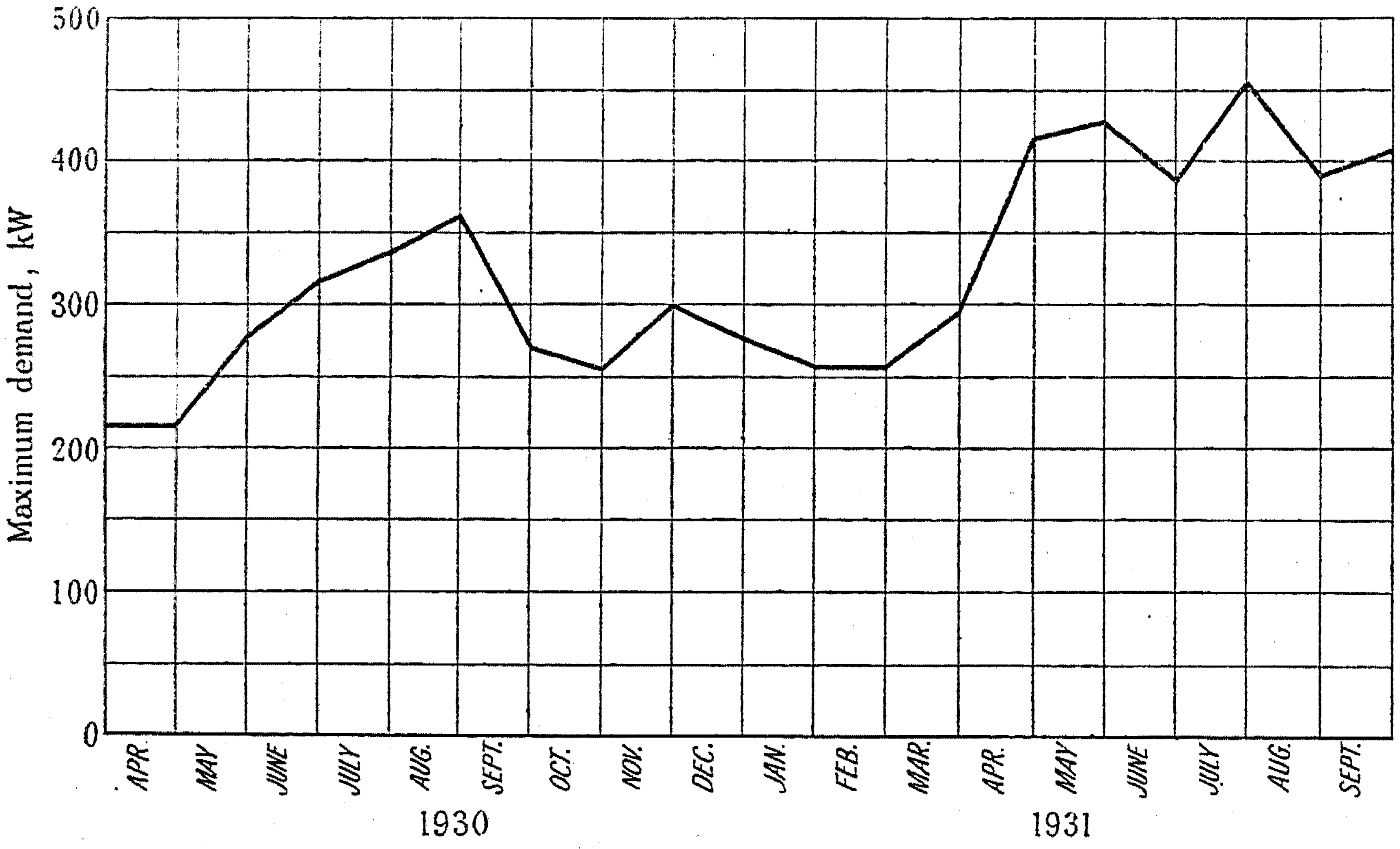


FIG. A.—Bedford rural demonstration scheme; maximum demand of six villages, viz. Oakley, Milton Ernest, Bromham, Clapham, Clophill, and Maulden.

rural and town dwellers. In order to get the proper data for our scheme it has, of course, been necessary to meter the current supplied to, and the maximum demand of, the villages; Fig. A is a monthly load-curve for six of the latter. The load started in April 1930 at a little over 200 kW. It rose steadily, and in the following September reached a peak of 360 kW. It then fell somewhat suddenly during October and November to about 256 kW. There was a slight rise in December and then a continuous fall to the end of March. After March the load began to rise again. We had a small peak in June and a large one (455 kW) in August. As in the previous year, the curve then began to fall again. This is exactly the reverse of what takes place in a town, for which the peak is in November or December. The explanation is, I suppose, that when the weather gets colder the cottagers wish to be cosy. They light their kitchen fires, and, being thrifty, do their cooking on these instead of on electric cookers. Our last reading is for the month of October 1931, and it shows a slight rise between September and October, although in 1930 there was a fall. We are anxiously waiting for the November and December (1931) results, to see whether this effect is repeated. It may be that the country people now like electric cooking so much that they have decided not to use the coal fires. On page 203 the authors draw the conclusion that the output increases when prices are reduced. This conclusion has been strikingly confirmed by the figures for our undertaking for the last completed year. About two years ago we altered the tariffs, making drastic reductions. We estimated that, without an increased consumption, we should drop about £10 000 per annum in revenue, but the results for the first completed year show an increase in revenue of £7 368 on account of domestic supplies, and an increase in the gross profits of the whole undertaking of £13 000. This may be due in a measure to the introduction of a 2-part tariff. The receipts from the flat rate for lighting dropped by £2 500, and those from the heating and cooking flat rate decreased by £221. The net result is very satisfactory, and is one instance, among many, of the principle that a reduction in the tariff is accompanied not only by an increase in revenue but also nearly always by larger gross profits. The authors suggest varying both the service and the running charge; an approximation to their suggestion is being made by a certain supply company which obtains the fixed charge by charging for so many units per £ of rateable value at a high rate, the number of units per £ of rateable value being reduced as the rateable value increases. I am told that this is a very practicable tariff. We always make use of the net rateable value for tariff purposes, and a leading valuer tells me that the gross annual value of a house is fixed principally on the basis of its floor space. The gross value having been obtained, certain percentage reductions have to be made in order to arrive at the net value. The percentage reduction on a small property is much greater than that on a large one, so that by charging on the net value we are rather apt to penalize the larger in favour of the smaller consumers. A graduated scale, such as is suggested in the paper, takes care of this point to a large extent. The authors state that the most economical area for rural electrification is about 400 square miles. An area of this size, however, is too large to be administered from one central organization; subsidiary centres are necessary in order to save transport and service charges. Even in our area, about 200 square miles, the difficulty of giving service to the consumers and controlling transport properly is great, and it is likely to be expensive if not carefully watched. It seems to me that the type of pole equipment we have chosen in Bedford is better in many respects than the one selected by the authors. The latter necessitates bird guards and has an eccentric loading on the pole, whereas the type of pole equipment we have chosen has a concentric loading and no three wires are in the same vertical or horizontal plane, which allows closer spacing. In addition, it was found to be cheaper than the authors' design. I should like to hear their further views on this point. With regard to the question whether transformers are able to withstand lightning, I should like to mention that one of our lines was struck some time ago by what must have been a direct lightning stroke. The fuses were renewed and the supply restored, but a week afterwards we found that the case of the transformer had been blown outwards and the cover bent up. The lightning had flashed to the cover, from two cambric leads inside, and the vapour pressure had actually stretched the middle of the transformer case out about 3 inches. The transformer was sent back to the makers and found to be undamaged. Coming to the end of the paper, the authors recommend intensive as against sporadic development of an area. I take it that the object of the Bedford scheme is to prove the wisdom of this plan. With this in view we are putting up lines all over the area, irrespective of the revenue we expect to get, we are connecting up everybody who wants a supply, and at this stage we are not worrying whether the revenue will cover the capital charges. This procedure has a great many advantages, and, if the undertaking can afford it, it is a very good thing. Whether we shall be able to prove that it can be afforded I cannot as yet say, but things are shaping very well and the consumption is increasing much more rapidly than we had expected. The first year's deficit is considerably less than the figure we had in mind. The figures for the year are roughly as follows. We sent out 1 656 000 units to the area, and sold 1 353 000 units. The total cost—excluding capital charges but including generation, distributing mains, cost of maintenance, apparatus on hire, selling, general development, showroom charges, management, meter reading, etc.—was £8 158, and the revenue was £10 436, giving a gross profit of £2 278. It has been difficult to allocate the capital charges because the area had been partly developed beforehand, but, subject to audit and approval, they amount to £3 293, leaving a net deficit of £1 015. This is something like half the deficit we had expected, so that the results have been quite as satisfactory as we had hoped. In conclusion, I should like to offer a word of caution on two important points. In addition to our own area we are giving bulk supply to a large surrounding area, and last year in particular had to meet heavy demands due to cold "snaps." We get the cold snaps from four or five towns, and while the cost of meeting the resultant heavy demands is comparatively small when the undertaking has its own generating station, it must be remembered that when we purchase electricity in bulk our kW charge will go up and we shall have to pay heavily for these cold snaps. They usually occur in January, the first month of the Central Electricity Board's year, so that we shall be penalized for the whole year on account of them. It seems to me that some other method will have to be devised by the Central Electricity Board for assessing the maximum demand, to avoid uncommercial penalizing of undertakings; an undertaker himself would find it quite impossible to sell current on these lines. While this paper does not mention the point, it has been said elsewhere that it is not necessary to give the same degree of reliability in rural areas as is done in urban areas and that the people in the former are so glad to get a supply that they do not object to a few failures now and then. This is, I think, quite wrong. At first, no doubt, they are delighted. They have a much better and less troublesome light than the oil lamps they had before, but when they get familiar with the use of electricity they will begin to grumble if the supply is interrupted, and, what is more, such interruptions will check development—especially in electric cooking. It is necessary to give the same degree of reliability in the rural areas as is given elsewhere, if we are to get the intensive development that we require.

Major T. Rich: The paper puts the problems of rural distribution into their proper perspective, for it contains less than one column connected with the grid supply of current, which many M.P.'s thought was going to solve all agricultural problems, and about 45 pages dealing with the difficulties to be overcome. If the paper had been available 5½ years ago, the present vast expenditure on the grid would probably not have taken place. There might have been many more villages with electricity supplies than there are, but they would not have been supplied on the lines of the present scheme. Even 5½ years ago it was well known, outside political circles, that the principal problem of rural distribution was not the supply of wholesale current, whether from a small station, or from a wholesale supply point, or from a super-station: the real problem was that of taking electricity from the wholesale point to the centre of the village or to the farm. Before the War there were approximately 20 000 villages in Germany with a supply of electricity, when grids and super-stations had not been thought of. We are told on page 190 that the capital charge per unit sold has fallen in 6 years from 0·42d. to 0·34d., although some people thought that it would fall almost to vanishing point. I believe that the capital charge per unit of a small station is not very different from that of a large station. One hears a great deal about the difficulties of obtaining wayleaves and about farmers who are asking high prices per pole or for allowing a transformer station to be erected on their land. When I was in Germany last year the head of a company which supplies an area nearly as large as Wales told me that the farmers there give pole and transformer spaces for nothing. In the standard form of that particular undertaking there is no provision for payment, because farmers who are without a supply clamour for electricity. The conditions appear to be similar in France. If the advantages which the farmer would derive from being connected were emphasized to a greater extent, it would do a good deal of good.

Mr. H. Nimmo: I congratulate the authors on producing a paper which will, I believe, serve for a number of years to come as a most useful guide to all who are interested in rural electrification. I would particularly commend it to the younger generation of engineers, who cannot fail to find in it a mass of valuable information which is not available elsewhere. For the success of their Model Scheme the authors have on page 192 assumed seven necessary conditions: I propose to confine my remarks to conditions (*a*), (*b*) and (*d*). The first requires that there shall be a cheap supply from the "grid." I understand that this is assured, but it would be interesting to hear what the Central Electricity Board and the power companies have to say on this point. The second condition requires that the capital cost of transmission and distribution shall be kept as low as possible by the maximum use of overhead lines. I think this is essential in sparsely-populated areas such as the authors have been considering. As regards amenities, I agree also that all reasonable criticism can be met by a careful selection of the route of the line and pole positions, and by a suitable arrangement of the conductors. It is the unreasonable criticism that is so difficult to cope with. Those engineers who have travelled extensively abroad and have seen to what an enormous extent overhead lines are used in other countries must, I think, feel as I do that this is surely the only country where such organized opposition exists to the erection of the cheapest known means of transmitting electric power. The amenities of beautiful countries like Japan, Switzerland, and Italy have not been spoilt by the many overhead lines to be seen there, and there is no reason why, with due care, the beauty spots in this country should be seriously interfered with. In referring to the Electricity Supply Acts and the Regulations issued by the Electricity Commissioners, the authors content themselves by saying that these on the whole offer no impediment to the designer in the selection of such material as will make for safe construction at moderate cost. Here, again, the unreasonable critic may disagree. We sometimes come across murmurings in the Press and elsewhere against the Overhead Line Regulations, but, except for certain proposals by one enthusiastic organization, concrete suggestions for improving the Regulations are rare. In this connection I would add that a great many of the overhead lines put up in this country have factors of safety far in excess of those required by the Regulations. Only a few days ago I saw an application for an overhead line in which the supports are to have a factor of safety of 9½ instead of the usual 3½. The authors' condition (*d*), namely the adoption of a suitable 2-part tariff, is the one which I regard as the most important. The authors have designed their Model Scheme for the requirements of a sparsely-populated area, and they have shown how it may be successful, but the tariff must be right and the unit charge in the 2-part tariff must be low enough to encourage people to use electricity for purposes other than lighting: in my opinion this should not exceed ¾d. per unit. We know, of course, it is less in one or two rural districts. My chief criticism of the paper is that it lacks a Model Tariff. The authors have, however, adopted in Table 19 the principle of a 2-part tariff based on the number of units sold, with an ascending fixed charge and a descending unit charge, and no doubt this will be a great help to those supply authorities who have not yet formulated a suitable 2-part tariff. Table 17 shows that a drop in the price of electricity to the consumer results in an increase of revenue. This is very important, and I was interested to hear that Mr. Phillips had found this to be confirmed by his experience. It would be well if the authors made it clear that this refers to net revenue. It would also be interesting if some of those pioneers in rural electrification to whom all honour is due, who led the way at a time when prices were not so favourable as they are to-day, and who have from time to time reduced their prices to the present low levels, would tell us the result of their experience in tariff reductions. While there are a number of supply authorities operating in rural areas whose prices do conform with the authors' requirements, there are a great many more whose tariffs are definitely discouraging to the equipment of all-electric houses. Table 10 shows that the revenue to be expected in the first year or two, principally from lighting, averages about £1 per room, and that the ultimate saturation revenue is approximately £3 per room. It would be interesting to hear how these figures compare with results obtained in practice. In his concluding remarks Mr. Kennedy gave some striking figures to show the enormous possibilities in areas still untapped. I would just add this with regard to the areas now being developed. What a wonderful prospect for the electrical industry if all those supply authorities whose tariffs are now so discouraging could be induced to supply at sufficiently low prices which would bring to them thousands of new consumers, and which would encourage the thousands of existing consumers who now spend from £3 to £6 per annum on lighting to use £10, £20, or £30 worth of electricity per annum in all-electric houses! Could not the Institution sift the valuable thought which is now being brought to bear on the subject of rural electrification, and issue some general recommendations?

Mr. C. F. Mounsdon: The paper deals principally with two subjects, rural electrification and tariffs. While a valuable conclusion is reached in connection with the rural electrification scheme, the same does not seem to be true as regards tariffs. Personally, I should have preferred to have seen a promise that tariffs would be referred to more fully in a separate paper. I am rather puzzled by the model form of tariff which the authors suggest, because in the report of the Electricity Commission Committee on the Uniformity of Electricity Charges, reference is made to the fact that a block tariff does not conduce to the use of electricity for purposes other than lighting. In my opinion such a tariff is contrary to the psychology of current-selling. The authors seem to have ignored conclusions which have reached maturity by virtue of experience, and have apparently made no effort to show why they should disregard the mass of data which has gone to prove the general impracticability of such a tariff. I should have welcomed a separate discussion on the question of tariffs, because it does not yet seem to have been possible to reach a definite conclusion regarding the basis of a 2-part tariff. In this connection even the suggestion put forward by the Electricity Commission, namely an outside-area basis, does not appear to have met with anything like general approval. I should be interested if the authors would make some further remarks on the question of their model form of tariff.

Mr. R. B. Matthews: The most important statement in the paper is that contained in the last paragraph of the Summary, which points out that electrification of sparsely populated rural areas is now a practical proposition from a technical and financial aspect. I am glad to see this statement, because it corroborates one that I have been making for a number of years based upon my own work. As a general criticism of the paper, I suggest that the authors do not seem fully to appreciate the importance of the farm load. Table 10 shows that they attach greater importance to the village public-house than they do to the village farm, the revenue from which is estimated to be less than that from a large residence and only equal to that from a large villa with 6 rooms: from the heading it would appear that the estimate for a villa of 6 rooms does not include power, whereas power is included in the farm estimate. With reference to the Regulations of the Electricity Commissioners, Table 25 shows some fairly high prices for transmission lines. Mr. Kennedy has mentioned some rather cheaper lines, but I have on my own estate an oak-pole line which cost about £120 per mile and an X-pole line which cost about £75 per mile. In America X-pole lines are now being erected at £60 per mile, but, owing to trouble with the 4 ft.-wide base, another form of line costing about the same (without overhead charges) is becoming popular. The overhead charges bring the capital outlay up to about £100 per mile. One of the reasons for its low cost is that, although wages are from 20s. to 28s. per man per day, with the aid of a 4-wheel-drive lorry having a pole-digger at the tail, 3 men only can dig the holes and hoist the poles into position. This enormously reduces the wage bill. The pole-digging mechanism, which is worked off the engine shaft of the lorry, operates through a vertical rod attached to the auger which raises the earth. The same lorry is used for hoisting the pole into position. I think, therefore, that an alteration of the Electricity Commissioners' Regulations El.C. 53 is required. The Overhead Lines Association has placed 14 suggestions before the Commissioners for modifying these Regulations, more particularly as regards rural work, which has to be done on a cheaper and lighter basis than usual if it is to be carried out at all. In view of their comparative magnitude, I should like to give a few illustrations of the larger uses of power on the land. (Mr. Matthews here exhibited a number of photographs by means of an epidiascope). There are now over 200 electric ploughs on the Continent, the largest of which are consuming 200 h.p., and a number of other applications are being developed which will materially alter the position as regards the use of current on the farm. An entirely new application of electricity, of which an example is shortly to be put down in Essex, consists of a large plant for dealing with the drying and disintegrating of green hay crops. This equipment will take about 150 h.p., and 600 acres of land will be required to produce the crop necessary to keep it fully employed. The crop will be cut continuously, giving factory-like conditions in the operation of the farm. Another illustration of factory-like methods on the farm is a travelling platform for milking cows. A further example of the large possibilities for the use of electric power on farms is one that renders the farmer independent of an adequate rainfall by shooting jets of water, by means of a " rain-cannon," all over the field. A 30-h.p. turbo-pump is required to operate this apparatus. I mention these various special instances, additional to the 300 farm uses of electricity of which I am aware, to emphasize the fact that if rural electrification is to be a success, the farm load must be regarded as a very important contribution to that success.

Mr. J. I. Bernard: Some doubt may be thrown upon the consumption figures assumed by the authors in connection with their Model Scheme. The figures obtained in practice for towns and urban areas are higher than those given by the authors, but in towns the average consumption is increased by large power users, hotels, shops, etc. I think, however, that full justification of the authors' figures for the consumption per consumer is found in the amounts which they have allowed in their expenditure and revenue accounts for management and publicity charges. This includes the cost of service to the consumer, an important factor in the successful development of a rural area. Electricity is a strange thing to rural dwellers; it has to be explained to them in a way that they can understand. The figures which the authors show for publicity over the 6 years fall off considerably towards the end of the period, so much so that I doubt whether the figure for the final year is sufficient to support a sales staff and showroom. Table 17 is a neat arithmetical proof of the advisability of reducing prices as much as possible. As the authors mention, hire-purchase and assisted-wiring schemes go a long way towards producing a high degree of saturation in rural electrification. In regard to tariffs, one supply undertaking operating in a rural area already has 2-part tariffs with various standing and running charges—the higher the standing charge, the lower the running charge. This kind of scheme would seem to cover what the authors have in mind in Table 19.

Mr. A. F. Harmer: The small domestic consumers are the most important because they are the most numerous and therefore provide the greatest turn-over, not only in rural districts but also in congested slum areas. This is indicated in Tables 7 and 10 and on page 196. Regarding areas which have not yet been reached by gas, the sooner the electricity supply is provided, the easier it will be for saturation to be effected (see Table 10). Supply authorities must, however, be prepared to quote an all-in tariff to include wiring and the hire of the apparatus, and the supply should preferably be slot-metered. Regarding pole fittings, I am in agreement with the authors as to the desirability of avoiding the drilling of holes. I would insist on clamp fittings throughout, particularly for the attachment of kicking plates. I am glad to see (page 217) that the authors prefer tap-changing switches to the ordinary tap links. Most transformer makers fit such switches without extra charge. They are very advantageous in any case, but particularly for outdoor transformers. I should like to confirm the remarks on page 219 referring to the oil fuse-switch, which I have advocated for the last five or six years, although it is only recently that it has come into its own. In my view, however, its design must be kept simple and robust, thus enabling a good article, which will give complete protection, to be produced at a low cost.

Mr. D. J. Bolton: With regard to the figures given on page 205, the authors state:—" The curve indicates the possibility of forming a 2-part tariff purely on a quantity basis." Figs. 9 and 10, however, refer to receipts from various undertakings, and not at all to costs. It is obvious that, in the long run, receipts must balance expenditure, but if, as in Figs. 9 and 10, one classifies receipts on a certain arbitrary basis, it does not follow that suitable tariffs will be obtained. One might, for instance, take receipts from brick houses and receipts from stone houses, and show that if a tariff were constructed on that basis the total income would equal the total expenditure: but that would be no proof that it was a sound basis. With regard to the tariff suggested in Table 19, the price charged to two cottages side by side, each taking 500 units per annum, would be 3·01d. per kWh, whereas the price to a larger house next door taking the same total as the two would be 1·87d., or only 62 per cent as much. That seems to me a quite unfair penalization of the small consumer. There might perhaps be a 10 per cent reduction for the larger quantity, but the aim should be to encourage the small consumer to purchase up to the maximum amount of energy suitable for his premises. It is no use penalizing a small consumer because he does not take as much current as a big one; if he takes as much as he reasonably can, he should have the benefit of a fairly similar price. I should also like to know whether the authors have compared the most economical section as given by Kelvin's law, or its extensions, with that given by considerations of voltage-drop. They twice say that dimensions of both transmission and distribution lines are fixed by considerations of voltage-drop; and this would naturally lead to the suggestion made by a speaker in the first part of this discussion, to put in voltage regulators and get the same result at much less cost. Taking the case of a type C village with a 50-kW load, however, and assuming an average load on the distributor of about two-thirds and a tariff of the kind cited, the most economical cross-section of conductor is just about the one the authors have chosen. It would seem, therefore, that in such cases it would not be economical to reduce the cross-section by installing regulators. The figure of 3 per cent taken for depreciation seems to be an error, that is for a 20-year fund bearing interest at 3·5 per cent. This makes a difference of £1 000 to £1 200 to the annual income, not a big item in the sixth year, but in the early years enough to turn a small profit into a loss. The financial results given in the paper seem on the whole to be unduly optimistic. While the paper shows that rural electri fication is commercially sound, I think that the selling price would have to be bigger than the one mentioned, or, alternatively, the undertaking would have to wait for a longer period and be content with rather smaller returns. I do not see how the return suggested could come from the sixth year. It remains to be seen whether our captains of industry will be prepared to supply capital on these terms.

Mr. J. P. S. Pillans: The authors state on page 201 that, for the purposes of the paper, it has been assumed that undertakers will be able to buy current from the Central Electricity Board at £3 5s. per kW and 0·20d. per unit. I am not concerned so much with the figures as with the fact that the basis of the demand charge is kW and not kVA. It seems to me that if the rural distribution scheme can purchase energy on a basis of kW of maximum demand, a large industrial consumer should be able to do the same. Seeing that in some cases the latter's load is the more valuable, due to the higher consumption and better load factor, there seems to be no logical reason for drawing a line of demarcation between the tariff charges to a rural electrification scheme and to a large industrial consumer. At the present time, the large industrial consumer is charged on a basis of his kVA of maximum demand, and he therefore corrects his power factor to unity in order to save money. If in the future, as the authors' statement seems to foreshadow, the basis is to be altered from kVA to kW of maximum demand, the new large industrial consumer will have no reason for correcting his power factor. Furthermore, the large consumer who at present corrects his power factor will probably be well advised to stop doing so. He may have spent many hundreds of pounds on synchronous induction motors and other power-factor-correcting plant which will be running at a low efficiency, and it would pay him to replace it by ordinary induction motors. Power-factor correction is principally in the hands of the large industrial consumer; if he stops correcting we shall have large factory installations working at about 0·75 power factor, and what with the numerous transformers throughout the national scheme, the power factor of the latter will be deplorable. The authors' qualifying statement as to power factor appears to be irrelevant, since if maximum demand is based on kW it must necessarily be unaffected by the power factor of the system. In brief, I can hardly conceive of the general adoption of the kW basis and I suggest that the paper should be based on £3 5s. per kVA. As this would materially increase the cost of energy, the authors have almost certainly under-estimated this important item, quite apart from the remarkably low figures they have taken.

Mr. H. Bentham: I do not propose to say anything about tariffs, but will devote the whole of my remarks to results. There are two distinct types of rural areas, one where the electricity supply authority must rely for its revenue solely upon the inhabitants, who all gain their livelihood from agriculture, and the other where it derives its income partly from industries which may or may not be allied to agriculture, partly from people who use the area for residential purposes only and not as a means of existence, and partly—but to a less degree—from agriculturists. Despite the fact that the two types of areas are very dissimilar as regards the prospects they offer to supply authorities, the authors base all their figures with regard to revenue and cost on the second type, i.e. an area which is practically an overflow either from a town or from an adjacent urban district. Table 6 shows that the total area in England over which distribution powers are authorized amounts to 34 000 square miles; whilst the total area of parishes with distribution powers in which low-tension lines are laid is 7 300 square miles, leaving over 26 000 square miles of undeveloped districts in which distribution powers already exist. Why has not this huge area been developed? The answer generally is: Because it depends entirely on agriculture, and agriculturists have not so much money to spend as the people in semi-urban districts. Table 9 shows two sets of figures, one taken from a Sussex village, and the other from a village in Worcestershire. So far as Worcestershire is concerned, the cottage is the residence of the agricultural labourer, whereas in Sussex practically no real agriculture is carried on and the type of people living in the cottages is generally not of the farm-labourer class. Sussex is the playground and market garden of London; therefore one cannot apply its revenue figures to, say, a typical rural area such as Lincolnshire. The expenditure of a small cottage in Sussex is shown as 4s. per week for 26 weeks per year, or £5 4s. 0d. per annum, whereas in Worcestershire it is 10d. per week, or £2 3s. 4d. per annum. The reason for this is simply that the one man can afford to pay £5 4s. 0d. per annum, and the other cannot. Mr. Matthews said that sufficient attention had not been devoted to farms and that according to the paper a farm produced a little less revenue than a public-house. That is quite true, the revenue from farms having so far been very disappointing. In a truly agricultural area a similar type of revenue will be obtained from all the cottages, and I therefore think that the authors have very much overrated the revenue to be expected. I do not think it possible to develop rural areas without assisted-wiring and hire-purchase schemes. The assisted-wiring scheme may either be worked by means of slot meters whereby the consumer pays an increased price per unit, or a deferred-payment system may be adopted. I agree with the authors that where there is no gas supply the country people welcome the introduction of an electricity supply, always providing it is accompanied by an assisted-wiring scheme. We have just run a line out to a small village where there is no industry of any description, and, of the 80 houses there, 63 have been connected in 4 months. I should like to know where provision has been made in the paper for financing the assisted-wiring and hire or hire-purchase scheme, as a very substantial sum would be required for this purpose. The authors base their costs on the assumption that the rural undertaker will obtain a bulk supply at £3 5s. per kW plus 0·2d. per unit. As a buyer of bulk supply I can assure them that these terms are not obtainable, consequently the costs side of their balance sheet is misleading. I should like to ask whether the remarks regarding the price of wooden poles hold good now that this country has gone off the gold standard. The question of wayleaves is brushed away much more easily by the paper than it is in actual practice.

Mr. F. W. Purse: Referring to the balance sheets at the end of the paper, the authors have assumed a bulk-supply price of £3 5s. per kW and 0·2d. per unit, whether the load is 477 kW or 9 746 kW. I cannot imagine this assumption to be correct. I know of a number of cases where—certainly for 7 years, and probably for longer—undertakings with rural districts in their areas are committed to buy from the Central Board at prices ranging from £4 7s. 6d. and 0·22d. to £6 5s. and 0·22d. I have heard of prices approaching the authors' figures, but in these cases the undertaking has had to carry also the capital charges on its generating station. I therefore suggest that the authors have under-estimated the cost per kW by at least £1. They have seriously under-estimated the cost of distribution and management. For comparative purposes I have taken from their balance sheet the figures for the sixth year of working, and also figures from vol. 7 of the Engineering and Financial Statistics issued by the Electricity Commissioners. For No. 1 Scheme I find that the total distribution and management cost is £8 565 for approximately 16 million units sold. The returns for existing undertakings of the same output are as follows:—Eastbourne, £20 192; Heston, £18 002; West Hartlepool, £17 040; Grimsby, £19 298; Swindon, £12 022; Gravesend, £6 725. Each of these areas is non-rural in character. They are not picked specially, but the figures for them are the nearest to those given in the paper. The figure for Gravesend is very low, but in that area there are only 5 426 consumers as compared with the authors' 9 530. They prefer to consider the number of consumers, and I will follow their example. As regards their No. 1 Scheme, the cost for 5 220 consumers is £5 815, or even lower than the figure for Gravesend, which is the lowest I can find. No. 2 Scheme estimates costs at £6 730 with an approximate sale of 11 million units. The nearest comparisons I can get for that output are as follows:—Ashton-under-Lyne, £11 908; Hornsey, £14 382; Nelson, £14 211; Barnsley, £12 043; Middlesbrough, £9 430. Again these are all considerably higher. No. 3 Scheme shows £5 300, with an approximate sale of 8 million units. Corresponding examples are:—Barnes, £12 056; Harrogate, £12 479; Dartford, £8 312; Kingston, £13 526; Eccles, £12 318; Stockton, £12 541; Stafford, £5 490. The figure for Stafford is the lowest, but is £190 more than the authors give. However, their figures cover 4 765 consumers, whereas Stafford has only 2 393. Dartford has only 2 090 consumers, and the costs for that area were £3 000 higher than the authors' estimate. To take another comparison, in the second year of their No. 3 Scheme the authors estimate a cost of £3 635 with 2 611 consumers, against Stafford's £5 490 for 2 393 consumers, and Dartford's £8 312 for 2 090 consumers. Taking into account all the varying characteristics of the towns quoted, there is substantial ground for my statement that the figures given in the paper for distribution and management are seriously under-estimated. The authors allow interest at only 4¾ per cent—too low a figure even for a public authority, and certainly a much lower rate than any at which a public company could borrow. Even in the case of the Galloway scheme where the loans are all guaranteed by the Central Electricity Board, the net cost is £5 7s. 6d. per cent. Finally, a sinking fund is taken at 3 per cent, which is, I suggest, an absolute minimum. My conclusions therefore are that if the balance sheet were re-cast, by adding the proper additional kW charge (which I am certain the majority of people would have to pay) and a figure for distribution and management in line with that of other undertakings, the balances would be quite different from those shown by the authors. I am, of course, basing my criticisms on the assumption that the Model Schemes represent self-contained rural-area undertakings. If, on the other hand, the authors have regarded each of them as an appendage to an existing urban supply area, it is obvious that part of the cost of the rural scheme is being borne by the urban supply system; in other words, the charges for the urban supply are being inflated in order to deflate the charges for the rural supply. I feel that it is a little harmful to those who are doing their best to run rural undertakings, to be told that after 6 years the price per unit can be reduced to as low a figure as 1·38d. Still, however much we may disagree with the figures, the paper supplies a framework which will enable us to lay out a rural electrification scheme in accordance with our own ideals.

Dr. A. Ekstrom and **Mr. V. Ekstrom** (*communicated*)*: We gather from the paper that those in charge of the national supply system are now tackling that most important problem, the development of areas where an electric supply is either non-existent or inadequate. The authors have shown clearly that if it is to be possible to give an extensive electric supply to rural areas in Great Britain at a cost which will prove attractive to the inhabitants and which, at the same time, will ensure a reasonable revenue for the supply undertakings, it is absolutely necessary to reduce the capital expenditure to a minimum. The lay-out of schemes for such a supply therefore requires careful investigation and a thorough knowledge of the basic factors for an economical supply. In high-tension systems (132 and 33 kV) the regulation of voltage is generally controlled by the introduction of special mechanical and electrical devices. In distribution systems for lower voltages, however, where such devices are seldom economically justifiable, the difficulty arises of combining a rigorously-planned economical scheme with a voltage regulation which ensures a satisfactory service to lamps and motors connected to the low-tension network. The problem of planning an economical rural supply and of the dependence of the latter on load, voltage, price of copper, energy losses, price of energy, and extension of the area to be supplied, is generally given little or no attention. The reason for this has been the lack, up to the present, of practical methods for studying how these factors affect the annual distribution charges of a supply and, eventually, the price of energy to the consumer. In connection with a projected rural scheme on the Continent for an area of about 6 000 square miles—i.e. about one-quarter of the size of the diagrammatic lay-out shown in Fig. 5 of the paper—we have made a thorough study of these questions, and our results may be of interest. In order to treat these problems analytically it is necessary to find explicit expressions both for the manner in which the dimensions of the various parts of a supply system, such as transmission lines, transformers, and transformer stations, vary with the load, voltage, price of copper, and price of energy, and also how the iron and copper losses vary in relation to voltage and load. The relations may be summarized as follows:—(*a*) The costs of different types of 3-phase transmission lines as a function of voltage, copper cross-section of the conductors, and price of copper; (*b*) the costs of different types of transformers as a function of voltage and load; (*c*) the total costs of different types of complete transformer stations as a function of voltage, load, etc.; (*d*) the copper and iron losses of transformers as functions of voltage and load; (*e*) the load factor of losses in lines and transformers as a function of the load factor of the energy supplied. Using as a basis figures given to us by several electrical manufacturing firms and contractors, we have found very useful expressions for items (*a*) to (*d*), by means of which the electric power transmission problems can be analysed from an economical point of view. Consequently, scope is given for working out the design of considerably cheaper and better-planned transmission systems than have hitherto been possible. We will briefly refer to a few of the results which have been achieved.

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* This communication was read at the meeting by Mr. A. T. Dover on behalf of the contributors.

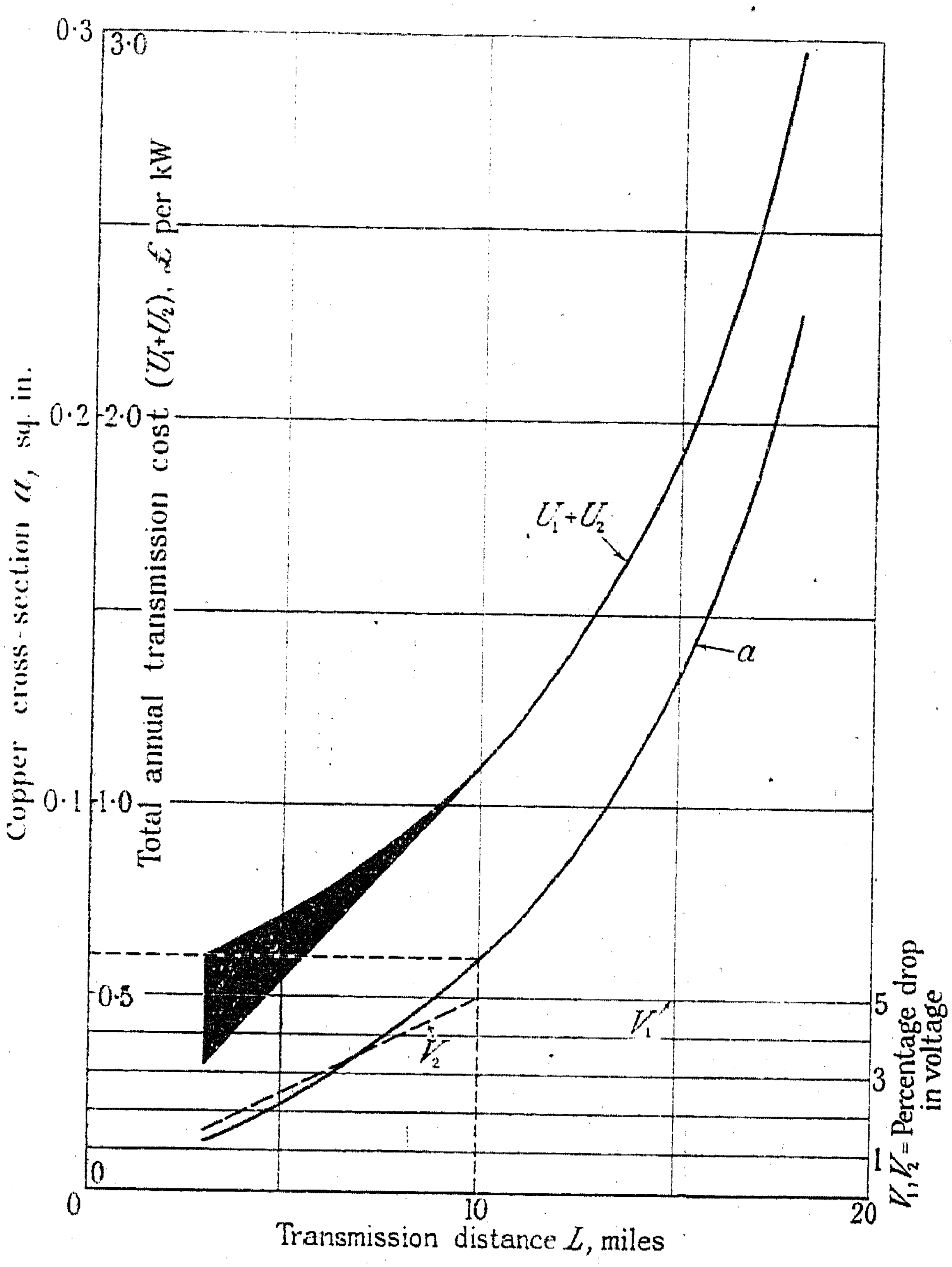

FIG. B.—Data for the transmission of 500 kW at 0·8 power factor by 11-kV, 3-phase, overhead line.

Example (1). Kelvin's law for the most economical current density in the conductors of a transmission line can be expressed in a useful form, showing its dependence on voltage, copper and energy prices, and the requisite percentage of the initial cost of the plant to cover interest and management charges. We find from this expression, for example, that if the price of copper were to fluctuate from £100 to £40 per ton (as has been the case during the past year), the economical current density would vary from 750 to 530 amperes per sq. in. This obviously has a substantial effect upon the copper cross-section of a transmission line which is to be erected, if it is to comply with economical conditions.

Example (2). Fig. B shows the copper cross-section (curve *a*) and the total annual cost per kW (upper curve $U_1 + U_2$) if a load of 500 kW at a power factor of 0·8 and a voltage of 11 kV is to be transmitted over various distances up to 20 miles, with a 5 per cent maximum drop in voltage (line V_1). If, however, a copper cross-section is chosen in accordance with Kelvin's law, although this will entail a larger cross-section (0·06 sq. in.) and consequently an increase in the initial capital cost of the lines, for distances under 10 miles the total annual charges on the lines will be considerably reduced (full part of curve $U_1 + U_2$, Fig. B). For instance, for 5 miles there will be a difference of more than 27 per cent. (The drop in voltage is shown by curve V_2.)

Example (3). When a transmission line is tapped at many points, as in rural electrification, considerable saving can be achieved by suitably choosing the dimensions of the cross-sections of the conductors in the various parts of the line. In a scheme which we have worked out for Lincolnshire 15 transformer stations (of sizes from 13 to 144 kW and at a distance from one another varying from 0·5 to 2·4 miles) are connected to an 11-kV line, the maximum permissible drop in voltage being 2 per cent. Different alternatives can be investigated, as follows:—(*a*) Where the cross-sections of the conductors are uniform throughout the line; (*b*) where the current density is uniform throughout the line; (*c*) where the cross-sections of the various parts of the line are chosen to comply with minimum transmission costs. Fig. C shows the cross-sections of the different parts of the line in each alternative, as well as the financial results as to weight of copper, energy losses, and total annual transmission charges. Alternative (*c*) gives a saving of 14 per cent, in regard to annual charges, as compared with alternative (*b*), and 20 per cent as compared with alternative (*a*). The saving is of the order of £100 for the short line under consideration. For the whole of the Lincolnshire area the total saving resulting from the use of alternative (*c*) instead of alternative (*a*) would be several thousand pounds.

Example (4). The authors investigate the data for the electrification of rural England and consider a Model Scheme based upon the average figures obtained from these data. We also have found the study of an imaginary area, the size of which is equal to that of an actual area but in which the distances between the substations and the loads of the latter are all equal to the average values in the actual area (i.e. the characteristic features of the area), to be exceedingly useful for this kind of research. For this purpose we have worked out explicit expressions by means of which the influence of different loads, voltages, distances between substations, and sizes of areas, upon the total overhead charges per kW or kWh transmitted, can easily be studied. We have introduced the figures given in the paper for the costs of rural lines, transformer stations, prices for copper and energy, etc., into the above-mentioned expressions for the area considered by the authors—i.e 400 square miles with 480 tapping points,* at an average distance from one another of 0·9 mile. For 11-kV lines of 0·05-sq. in. copper cross-section, with a maximum drop in voltage of 4·5 per cent, our formulæ give an average maximum load of 38 kW available at each tapping point, whereas the authors show a figure of 30 kW. Their calculations therefore seem to us to be very conservative. It is obvious, however, that it is not economical to give the 11-kV lines the same cross-section over the whole area [see alternative (*a*), Fig. D]. It can be shown that even with a considerable increase in the copper cross-sections in the main distribution lines radiating from the transformer stations [see diagrammatic lay-out, Fig. D], the annual overhead charges per kW transmitted will remain unaltered, whilst a considerable reduction in the maximum voltage-drop will be achieved. We illustrate this by three examples:—In alternative (*d*) the copper cross-sections of the main distribution lines

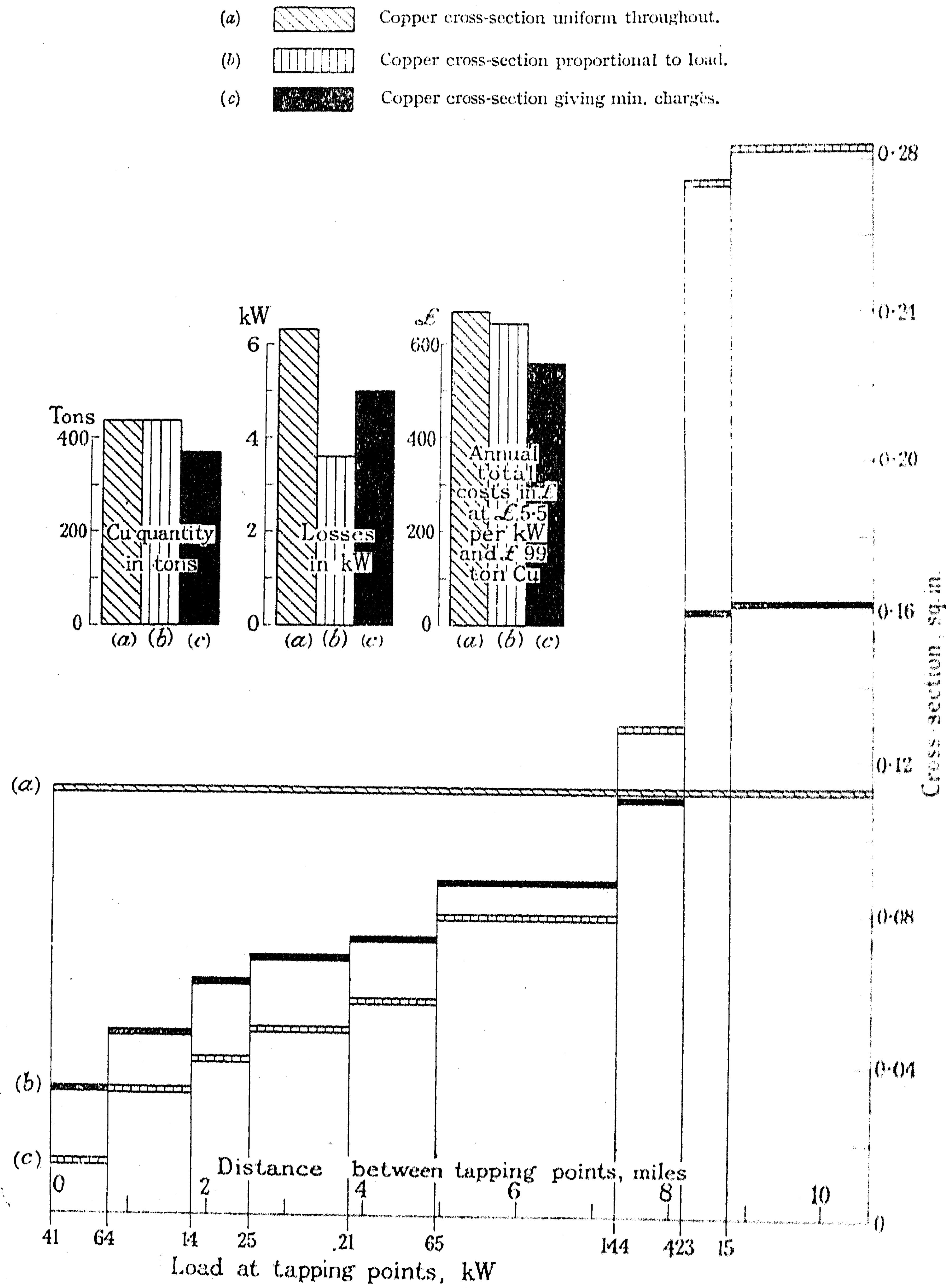

FIG. C.—11-kV line tapped at 9 points.

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* The authors assume that the industries are placed close against the main 11-kV lines, so that no distribution lines are considered necessary for them. One village and one industry ought, therefore, to be regarded as one tapping point (or 96 tapping points in all) when calculating and deciding upon the dimensions of the necessary distribution lines. These 96 tapping points with the 384 isolated equipments for farms and residences give the total of 480 tapping points.

are chosen to comply with Kelvin's law. In alternative (*e*) the copper cross-sections of the main distribution lines are chosen so as to give a minimum drop in voltage when the minimum copper cross-section is 0·05 sq. in. In alternative (*f*) the copper cross-sections of the main distribution lines are chosen so as to give a minimum drop in voltage when the minimum copper cross-section is 0·04 sq. in. Fig. E shows that in the four alternatives the total annual distribution charges per kW transmitted are similar. In alternative (*a*), however, the maximum drop in voltage is 4·5 per cent, in alternative (*d*) it is 3·4 per cent, in alternative (*e*) 3·03 per cent, and in alternative (*f*) 2·49 per cent. This shows clearly the importance of having a systematic lay-out for a distribution system.

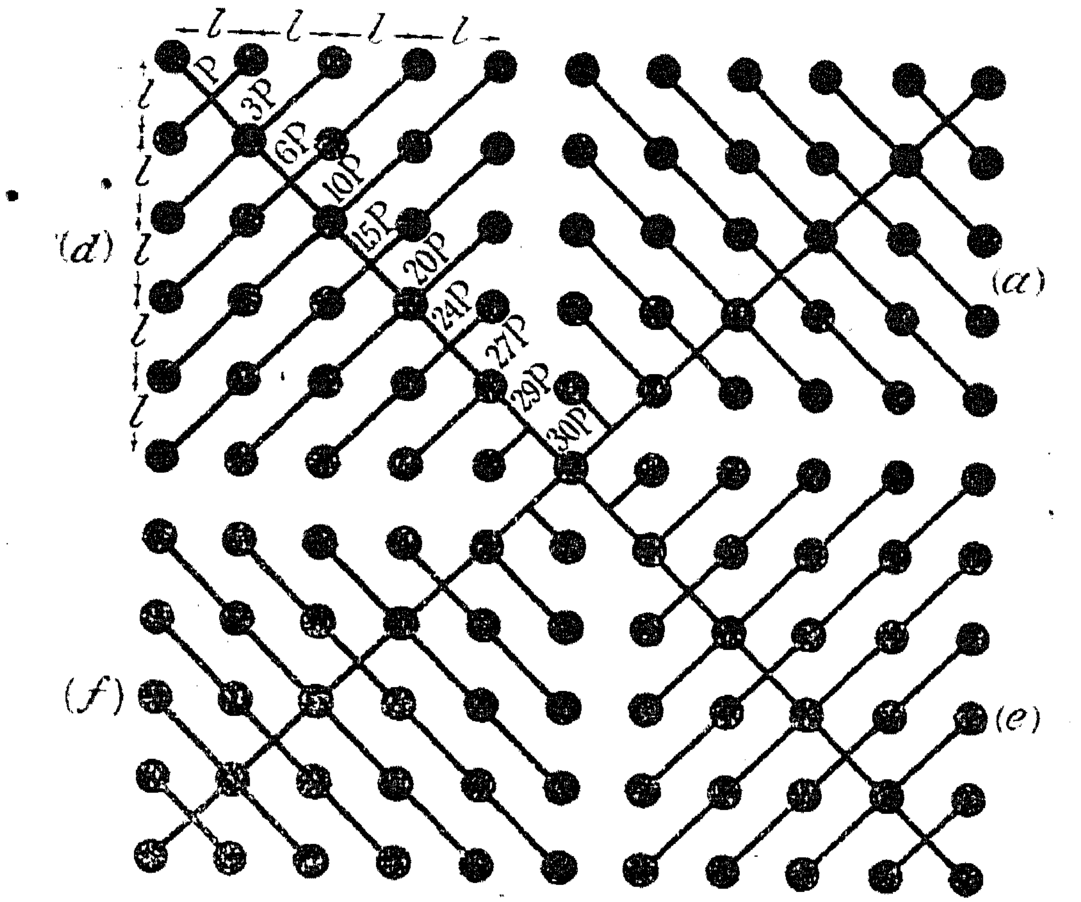

FIG. D.

Example (5). It is also possible to ascertain how the maximum permissible drop in voltage should be divided between the h.t. transmission system (e.g. 11 kV) and the local l.t. network (e.g. 400 volts) in order to satisfy the condition of minimum annual charges. In the case considered by the authors the ratio of the voltage-drop in the 11-kV lines to that in the low-tension distribution network (400 volts) should be as 4 : 10 and not 4·5 : 4 as assumed in the paper, if an economical lay-out of the two schemes is to be achieved. By introducing the methods indicated above, it is possible to analyse problems of this kind in a strictly

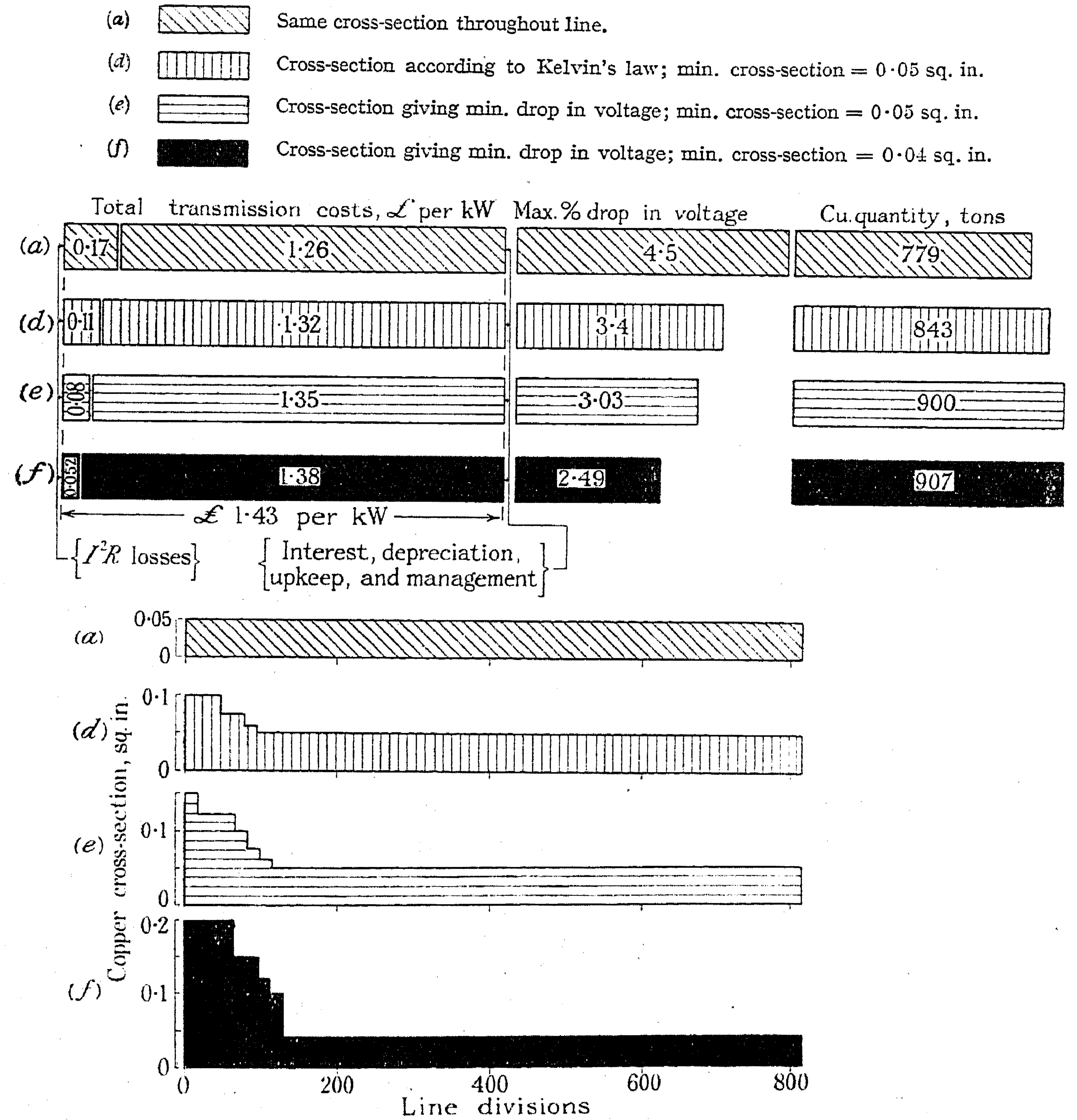

FIG. E.—Transmission costs in 11-kV rural lines.

Total area of district = 400 square miles.
Number of tapping points within district = 480.
Average maximum load per tapping point = 38 kW.
Average distance between tapping points = 0·9 mile.

mathematical fashion. We therefore consider these methods to be of particular value for the lay-out of rural schemes, for which, up to the present, the unsatisfactory method of trial and error (mentioned on page 209) has prevailed.

Mr. R. Grierson (*communicated*): Two important messages which the paper contains are: first, "Think big" (see page 197, col. 1); and second, (*b*) "Stop thinking in bits" (page 206, col. 2). The following is an interesting example of lack of vision and foresight. In a London suburb where the tariffs are excellent, land was developed by the erection of detached houses of the £1 500 class standing on an average frontage of 60 ft., and cables were duly laid. Four years later—on receipt of a demand from one of the residents for current for a 6-kW cooker, two or three heaters, and a water heater—it was declared to be necessary to dig up 60 ft. of made garden path, the pavement, 26 ft. of roadway, and part of the opposite pavement, in order to give the supply. Facilities for balancing the load across the three phases were demanded, but on its being pointed out that the house contained only six rooms, and that the dimensions of the kitchen (the only place available for the switchgear) were only 10 ft. × 11 ft., that it contained two doors, a 4-ft. window, a fixed dresser and a fireplace, and that there was positively no space for three double-pole switches and three double-pole fuseboards, a compromise was arrived at by connecting the cooker to one phase, the remaining heating and lighting load to another phase, and leaving the third phase unloaded. The possibility of carrying connected loads of from 10 to 15 kW on one phase requires careful consideration, because it is very undesirable to introduce the 400-volt supply into these small houses where space is so restricted. I am particularly interested in the authors' reference (page 201) to the cost of bulk supplies, because experience indicates to me that several engineers who are now receiving bulk supplies at rather onerous charges under long-term agreements, from neighbouring undertakings or from power companies, are afraid to take an optimistic view of the situation for the unexpired term of their agreements. This naturally retards development, and every step should be taken to dispel this pessimistic view at the earliest possible moment, provided that there are adequate reasons for the views expressed by the authors. The problem is complicated in some instances by the fact that additional plant has been installed to give the bulk supply and would not be required if the agreement were terminated; in other cases several miles of line have been erected at the supplier's expense, and would become obsolete if a supply were taken from the grid. Regarding the question of tariffs to domestic consumers, we must do everything in our power to dispel the atmosphere of mystery that surrounds our craft. Decimals are anathema to the average housewife and to the average rural consumer, but an easy way out of the difficulty is to quote the number of units obtainable per shilling. Thus instead of 0·86d. per unit, the price would be 14 units per shilling (see Fig. F). This elementary consideration of psychology seems to me to be important in connection with domestic and rural development, for fear of the unknown must inevitably retard development. The authors' statement (page 224) relating to the earthing of the l.t. distribution systems will be disconcerting to many engineers. Some more definite lead is desirable on this important question. Only a few weeks ago it was suggested to me by a supply engineer that I should earth the neutral of an installation through an ammeter, with a fuse connected in series to protect it. Both the New Zealand and the U.S.A. engineers recognize multiple-earthed neutrals, i.e. neutrals earthed at the transformer, at one or more points along the distribution or service line, and at each consumer's premises. English engineers who have studied the subject closely are in favour of multiple-earthed neutrals, because when they are adopted electrolysis is absent, interference with signalling circuits does not seem to materialize, voltage-rises between earth and neutral are prevented, phase lines operate at the declared voltage to earth (and therefore failures of apparatus and materials designed to operate on 230-volt circuits do not occur by reason of rise of voltage), concentric systems of wiring with single-pole overload protection and single-pole switching become practicable, it becomes difficult to insert single-pole switches in the earthed (or neutral) conductor, the safety factor is materially improved, and the cost of the installation is considerably reduced. The adoption of multiple-earthed neutrals means that earthing of exposed metal which is liable to become alive is no longer an onerous business; an earthed electric radiator is merely connected with two conductors—the phase line and the earthed neutral. The phase line is connected to the live side of the element, and the earthed-neutral core of the flexible cord is paralleled on to the metal framework and on to the neutral terminal of the element. Some definite and authoritative lead must be given on this question; we must either regard the neutral as an earthed, dead, and entirely innocuous conductor, and the phase line as being restricted to a voltage of 230 volts to earth, or we must insulate the neutral for a pressure of 230 volts to earth, fuse and switch it accordingly, and insulate all phase lines for a voltage of 400 volts to earth. I admit that the phenomenon of excess voltage only occurs at irregular intervals, but since it occurs it must be provided for. Many fires, failures of switch gear and fuse gear, and breakdowns of installations, can be shown to be due to the variation of voltage from declared conditions (on the development of faults); these fires have occurred where the neutral has been

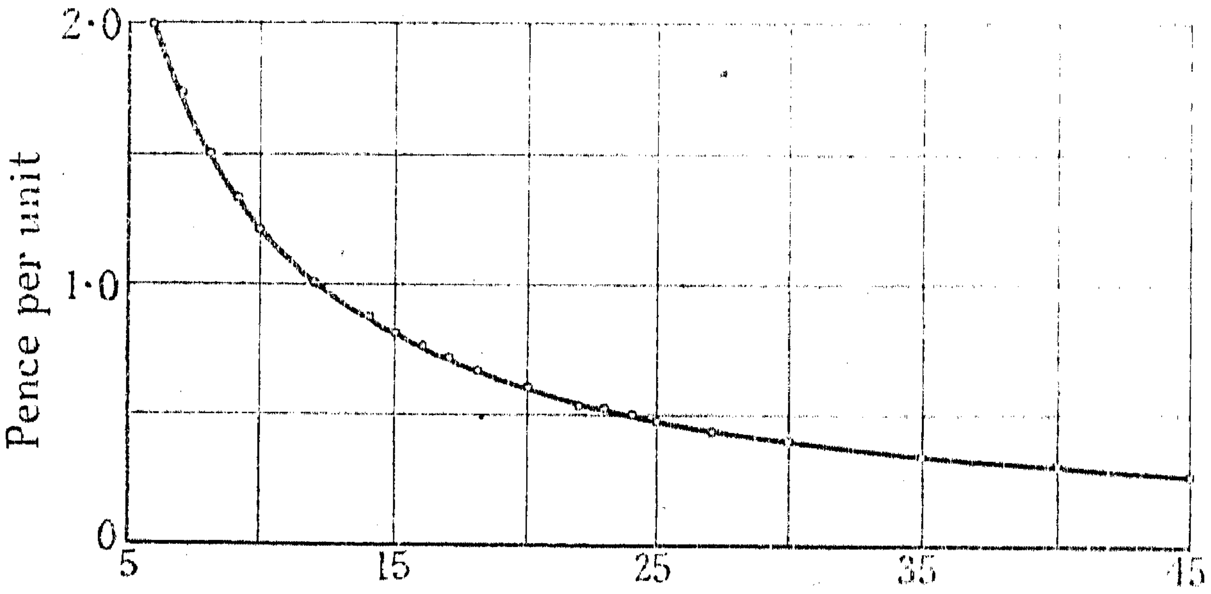

FIG. F.

earthed at one point and also, in many cases, through a resistance. Analysis of the data given on pages 226, 230, and 232, provides the following interesting figures:—

Population per sq. mile	150	100	75
Cost of e.h.t. lines (£)	151 472	130 700	103 925
Average cost of e.h.t. lines per consumer (£)	15·9	20·2	21·8
Cost of transformer equipment and switchgear (£)	41 092	30 032	22 344
Average cost of transformer equipment and switchgear per consumer (£)	4·3	4·65	4·68
Cost of l.t. lines, services, and meters (£)	93 494	66 694	52 666
Average cost of l.t. lines, services, and meters, per consumer (£)	9·8	10·3	11·0
Total cost per consumer (£)	30·0	35·15	37·48

Analysing the same tables for installed transformer capacity, kW bought, and average kW per consumer, the following figures are obtained:—

Population per sq. mile	150	100	75
Transformer capacity installed (kVA)—			
(*a*) Village	6 240	4 400	3 620
(*b*) Isolated	1 920	1 440	960
(*c*) Industrial	3 360	2 208	1 632
Total	11 520	8 048	6 212
kW bought (6th year)	9 746	6 592	4 873
Equivalent kVA at 0·9 power factor	10 800	7 320	5 420
Percentage kVA bought to kVA transformer capacity installed	94	91	87
Number of consumers	9 530	6 446	4 765
kW bought per consumer	1·02	1·02	1·02

The percentage of kVA bought to kVA transformer capacity installed appears to me to be very high and to presuppose a high degree of organization. And now a word as to the end of it all. In the electrical industry the enormous boilers, turbines and switchgear, the hundreds of miles of grid lines, the step-down transformers, the tens of miles of 11 000-volt and the miles of 230/400-volt lines, have all been erected to boil a kettle, heat a lamp filament to incandescence, or maintain a radiator element at a bright-red heat. Millions of pounds are being spent on the works that generate the energy, and on the lines of communication along which the energy flows. The authors rightly stress the high cost of maintaining a 4 per cent or even a 7 per cent voltage regulation at the consumer's terminals. To me it seems incredible and illogical that we engineers should be content to allow the last few yards of this highly intricate, costly, and elaborate structure, which lie between the house service box and the kettle, lamp, or motor, to be installed in any way that a garage hand, ironmonger, plumber, builder, chauffer, or "intelligent" boy considers to be satisfactory. In effect, these last few yards are in many cases allowed to negative the efficiency of the service on which so much time and thought and money have been spent.

Mr. H. Willott Taylor (*communicated*): The efficient carrying-out of the preliminaries in connection with a high-tension line is a vitally important point which the authors have not emphasized. More money can easily be lost through an inefficient method of dealing with these preliminaries than one can hope to save by reductions in the cost of actual constructional work. The successive steps to be followed, I suggest, are:—(*a*) A rough survey of the whole area to ascertain approximately the location and magnitude of the loads immediately and ultimately available. (*b*) Approximate route of lines to complete the network to be shown on a 1-in. Ordnance Survey map, prior to examination on site. (*c*) Actual lines for wayleaving to be shown on 6-in. Ordnance maps, after careful examination on site as to the best routes to be followed to pick up all available loads. In this connection, it is not always realized to what extent a line can be deflected so as to avoid the erection of a spur line, and at less cost than is involved by the latter. In other words, as a general rule it is better to zig-zag a line through an area to feed the various load centres than to run it fairly straight and erect numerous spur lines. An additional advantage of this procedure is that a duplicate supply is available to all transformers if the line ever becomes part of a ring main. (*d*) After the wayleaves have been obtained (and sometimes simultaneously), a profile of the route should always be made. Such a survey may cost from £5 to £15 per mile, depending on the contour of the line. In practice this amount is usually more than saved in the cost of the line, as the survey enables one to take advantage of any undulations by lengthening spans and so reducing the number of poles. It also makes one sure beforehand of having poles sufficiently long to give the required ground clearances and avoid uplift. (*e*) To reduce the cost of construction to a minimum it is essential to have all wayleaves clear and all material on site before the constructional work is actually started. The

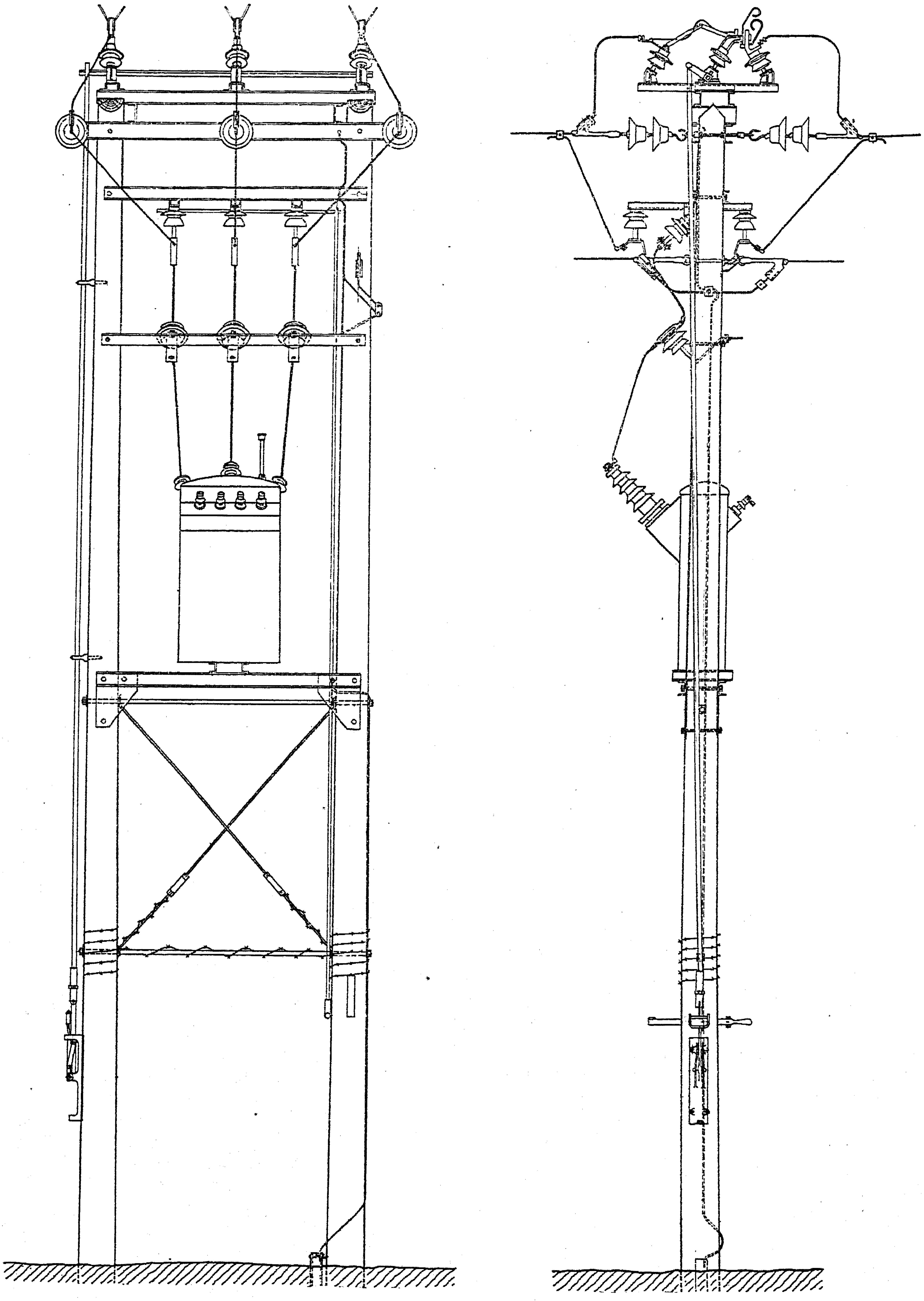

FIG. G.

figures for the cost of lines given in Table 25 would appear reasonable when it is remembered that they are based on the assumption that about 200 miles of line are to be erected, and that the figures make no allowance for wayleaves, survey fees, and compensation claims, and very little for tree-cutting, Post Office crossings, and other contingencies. This table may be misleading unless it is realized that the figures mentioned are only applicable to a perfectly straightforward line with no haulage, erection, or other difficulties, which normally occur and may considerably increase the cost. It may be of interest to record that many miles of 7/12 S.W.G. copper-cored steel (80 tons tensile strength) lines with light "A" poles and normal spans of 700 ft. have been in service for about two years, and have been trouble-free. The ease with which undulations in the contour can be taken advantage of by providing two poles of slightly increased diameter and if necessary varying the conductor spacing, so as to enable a span of, say, 900 to 1 000 ft. to be used, is a strong recommendation for this type of construction and enables the total cost of the line to be reduced. Although a saving is effected by earthing each pole individually, particularly when (as mentioned above) spans of 700 ft. are used, I prefer to run a continuous earth-wire, because it reduces the likelihood of lightning trouble and also ensures a more effective earthing of switch handles, which are often situated in places where efficient local earthing would be very difficult. I am surprised that the authors make no mention of the "wish-bone" type of fitting for single poles, as this is cheaper, involves less pole drilling, and is neater in appearance than some of the types illustrated. It is unnecessary to fit another cross-arm for medium-angle positions, as suggested for the type shown in Fig. 20. A cheaper and better way is to support the two insulators at the end of an additional, short, straight strap bolted in the middle to the cross-arm, thus allowing the insulators to lie in tandem, and if the fixing bolt is not finally tightened until the line has been tensioned, the strap will pivot on the fixing bolt, thus ensuring that the insulators share the load equally. The same method could be adopted for the top fitting, to obviate the necessity of drilling its sloping sides and so weakening it, and it could also be followed at road crossings to obviate the necessity of having specially-prepared cross-arms for the purpose. A reduction in the number of special parts results in lower erection costs. Do not the authors agree that for straight-line section poles the fitting of pilot insulators to carry the jumpers round a single pole is quite satisfactory, and much cheaper than providing an "H" pole? Has either of the authors tried to operate by means of a pole at night and with a moderate wind blowing the type of switch-fuse shown in Fig. 25? If so, their experiences would be of interest. As regards Fig. 27, I question the wisdom of providing fuses for every transformer. Transformer faults (from which the fuses are intended to protect the main line) are so extremely rare that the cost of the great number of fuses required is unwarranted for the occasional service an individual one would render. It is therefore good practice to fuse only long spur lines and fit a simple isolating switch to the individual transformers. Fig. G shows a type of construction particularly suitable for a 50- or 100-kVA transformer on a ring main. The saving in switchgear effected by incorporating one set with change-over features to control the transformer should be noted. On low-tension overhead lines experience has shown that the practice of fixing the insulator in a horizontal position by a bolt passing right through the pole facilitates erection, is cheaper, and improves the general appearance. An insulator with a rather deeper conductor groove than normal is an advantage, as quite appreciable angles can then be taken before any strain comes on to the binding, the pole always being fixed on the inside of the angle. The method of tapping the line is shown in Fig. H.

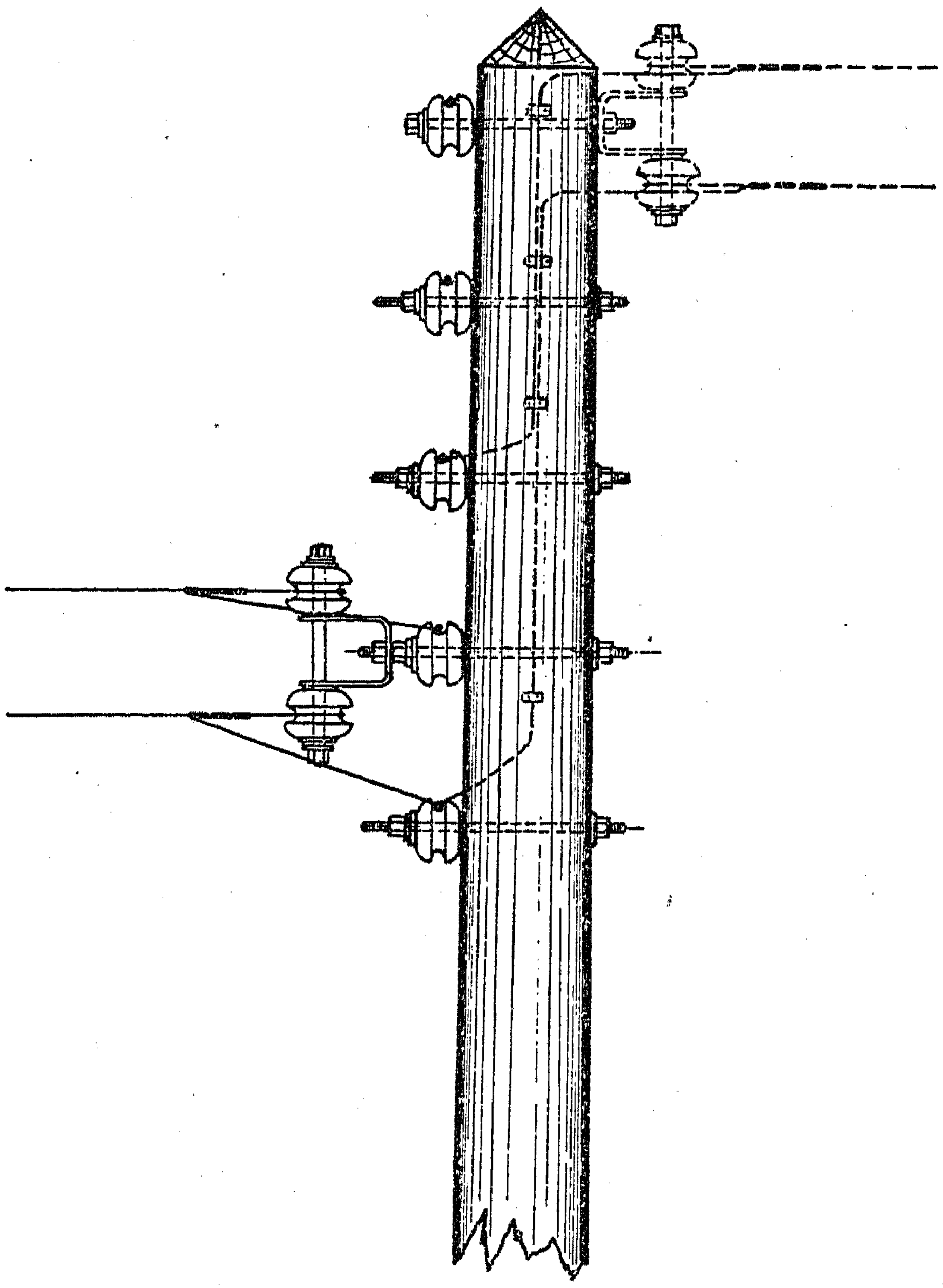

Fig. H.

Mr. W. T. Taylor (*communicated*): While we may not accept the authors' Model Scheme as a true basis to guide us, we have to admit that they are successful in painting a pleasing picture by methods and means which engineers have wanted, and been begging for, for many years. The electrification of rural areas in this country has until recent years not been generally considered to be a practical proposition from the financial standpoint. A "well-considered system" (from the authors' point of view) executed under the older regulations would almost certainly have led to financial failure. The area covered by, and the number of people served in, a rural area are less important than the kWh consumed or the revenue earned. Tapping all sources of revenue, without due regard to the revenue and money spent, may mean ruin. The ever-present question before electricity authorities is: Will it pay in a given period? Our conceptions of this problem vary somewhat. Educational propaganda is more important than covering a large area. If by means of suitable propaganda the people living in rural areas can be made more electrically minded, they will use more and more electricity. In general, the average kWh consumption per consumer in a town is greater than that in a village or parish. To complete their Model Scheme the authors assume a minimum area of 400 square miles, a certain population density, kWh consumption, and the averages of various factors. We may average designs and types of lines, etc., for a given voltage and load, but we cannot very well average the mileage of lines and kWh consumption in every rural distributing centre, or the mileage of distribution to serve a given load for the same number of consumers, or the rate of load growth and class of load and population to suit every rural area of the same total overall dimensions. In numbers of cases there may be wide deviations from the mean values. Every 400-square-mile area has its own distinctive shape and costs for best electrification, and its own economic possibilities. Each such area must be studied separately and developed along more or less modified lines as new mains or extensions are deemed necessary or commercially advantageous. The construction of new lines or extensions is best limited to areas where they can be most economically erected and used to the full capacity within a fair period of years. Therefore, sporadic development has been, and may often be, the quickest or the best possible solution. In estimating kWh consumption the authors credit to industrial consumption a large percentage of energy sold, and they apparently do not properly take into account the fact that industry can decrease with or without increase in population. Do not present-day industrial conditions prove this contention to be correct? In estimating the future load growth in untouched rural areas, the percentage annual increase is not easy to predict. The percentage increase in population is likely to be less rapid than past records show. Also, the future kWh consumption per head of rural population (or per consumer) may show a vastly different relation to past records for towns. The best model scheme (either for a machine or for a system) is usually based on a specific set of fixed conditions, and the design—such as the authors' Model Scheme—to suit best the fixed and variable conditions involved, is most likely less accurate than (and will depend upon) the state of materials, standardization,* etc. Our knowledge of tariffs, generating costs, and designs, is such as to place British engineers well in line with the world's most modern work. A few years ago money was cheaper and more plentiful, and generation costs were lower than to-day, yet rural development was delayed. What was the cause? The authors avoid details of the real cause because they, perhaps like many others, are sufficiently satisfied to know that we are now allowed to put up cheaper overhead lines in much larger numbers. The wood pole still deserves preference, but from the operating standpoint full use is not taken either of its insulation value or of the insulation of cross-arms. Why use bird guards, when the extra expense and anxiety they involve can be avoided? Compared with the cost of a pole, the cost of a cross-arm (upon which the line depends) is a very small item, and a few more pence may well be spent upon it. If it is definitely accepted that bird troubles are a worry and an expense, why not use the forms of cross-arms shown in Figs. 17 and 20, or in Fig. J, for metal or concrete poles? Such forms are quite as strong and secure as the flat cross-arm. The authors recommend the adoption of copper conductors for l.t. lines, and steel-aluminium conductors for h.t. lines. Their outstanding claim for the use of steel-aluminium is that wayleave costs and difficulties favour the longer span for primary lines. This practice demands more highly stressed insulators and higher line-supports, etc., which are disadvantageous during the whole life of a line. I have no hesitation in recommending the use of galvanized-steel conductors, which have a smaller initial cost and greater mechanical strength, on certain small current-carrying capacity 11 000-volt lines. The use of a high voltage is advantageous because it permits of placing electrical conductivity in a less important position than mechanical strength of conductors. The annual loss in revenue due to energy loss, or line voltage-drop, should more generally decide what conductor metal is the best and most economical. Are not the authors' figures for line mileage, gross electrification cost, load, and tariffs, too favourable? Figures and facts from actual practice will give these in their true perspective for each case, and it is unjust to average each variable factor to fit equal areas of different shapes, etc.

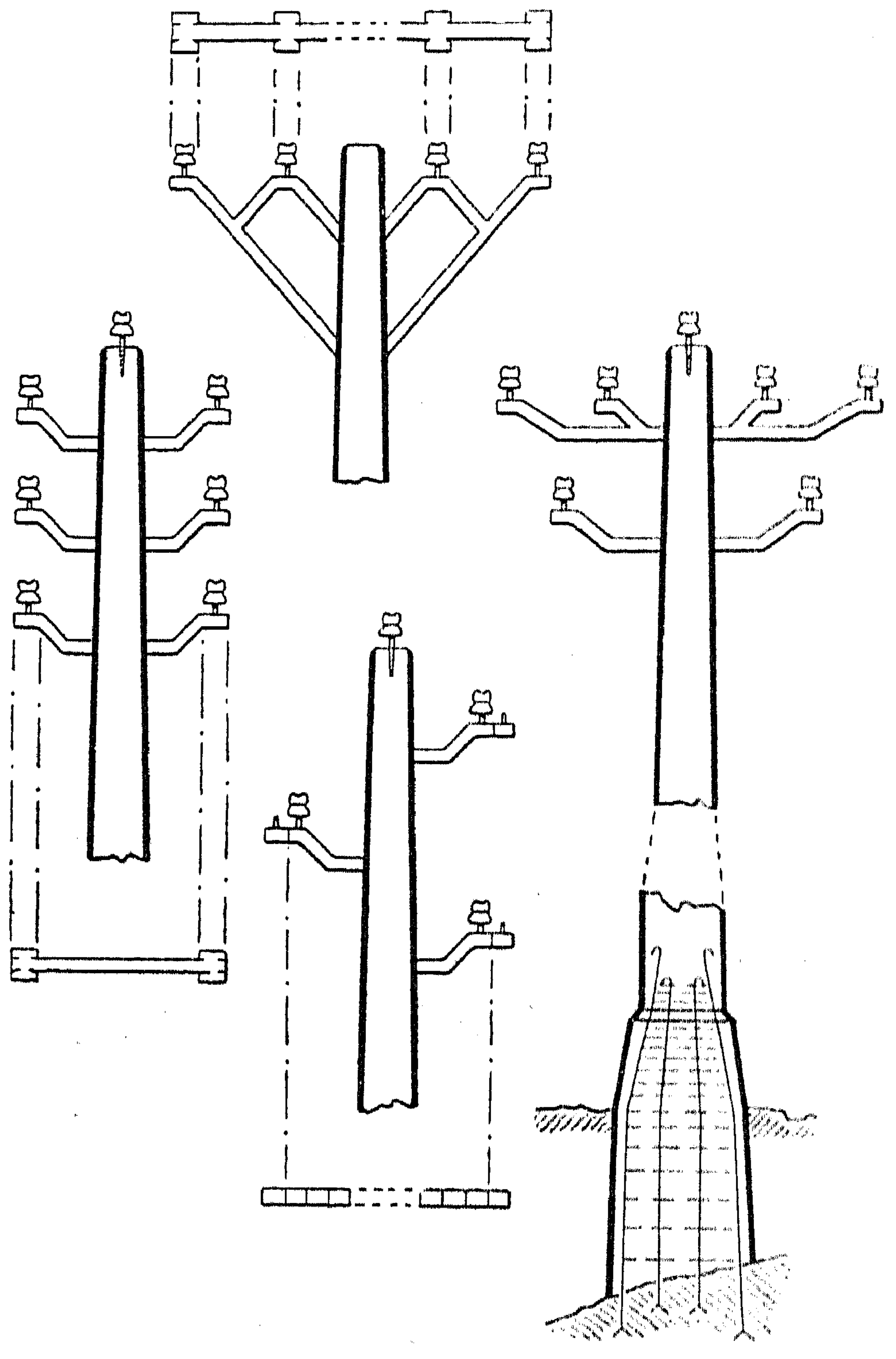

Fig J.

Mr. W. A. Turnbull (*communicated*): The novel tariff suggested by the authors calls for some intensive thinking. They seem to have plotted a line for lighting units almost vertical, and a line for the other uses almost horizontal; the two quantities are totally unrelated, and because a mixture of the two fills in the bend they have called it a "hyperbolic" curve. I am using the base-area 2-part tariff, with the high alternative flat rate of 10d. per unit. Much revenue would be lost by adopting a flat rate of 6d. per unit. I think that the electrical unit of area of 100 square miles is too small; the Central Electricity Board will not place substations on the average at such frequent intervals. At 11 000 volts electricity can be transmitted in quantities much above the demand in rural areas for distances of 10 miles, not under 5 miles as suggested by the authors. This would increase the length of 11 000-volt lines required, but at a much less cost than that of the extra Central Electricity Board lines and substations. The design of the pole fittings (Fig. 18) chosen by the authors is not neat; it is too top-heavy. The top wire should be lowered considerably. This reduces the size of pole required. Bird guards look clumsy and are an unnecessary expense. I use long pins and dispense with the two bottom struts, except at bends. The top bracket should be central with the pole as in Fig. 20, and not stuck on one side, as in Figs. 21 and 22. The authors' adoption of 3-phase short-span copper spur lines I consider to be a vital mistake. Single-phase steel wire having 400-ft. spans should be adopted; this will transmit more electricity than will ever be required. The depreciation of steel wire is less than that of copper wire; copper has a scrap value of not more than half its first cost. Steel costs less than half copper, so that even if the obsolete steel is of no value the depreciation involved is less than that in the case of copper. The 5–15-kVA transformer arrangement (Fig. 25) is wrong. A single-phase type should be used and the linesman should not be expected to insert the operating rod into a 1½-in. hole 20 ft. above, and especially over the top of, the live conductors, down to the transformer. The fuses should be on the opposite side to the transformer, and the man should be allowed to climb the pole and operate with a smaller rod. I admit, however, that the drawing looks very neat. To use h.t. cable with the larger transformers is not only costly but a source of weakness. High-tension pole boxes cause more annoyance than birds or storms. The authors, have, I think, accepted the next best design for their l.t. distribution. The best type is the Aylesbury pole, with its neat, balanced appearance and no metal fittings to bond. The wayleave question is lightly put to one side in the paper, although it is a very serious obstacle. In actual fact, the figure of 1s. 3d. per pole mentioned on page 228 should be about 5s. per pole. With regard to wayleaves, if the result of a recent compulsory application to the Electricity Commissioners for a simple farm-land wayleave had been accepted it would have meant an extra charge of about £600 per annum for wayleaves. Fortunately I was able to take advantage of another, but very costly, route. Single-phase distribution is not referred to in the paper. For rural villages with populations up to 5 000 I strongly advise a 3-wire single-phase system. Copper for copper, it is as efficient as 3-phase distribution. A reduction of one wire makes for a much neater and cheaper system. The small amount of energy used for power purposes can be efficiently dealt with by means of 460-volt single-phase motors. Should a factory come to the village the mains system could be divided on to the two halves of a Scott-connected transformer and 2-phase power supplied to the factory. It is difficult enough to balance on the two circuits the few cookers obtained; it would be a serious difficulty with three circuits. Voltage regulation is considerably assisted by using static balancers, which for single-phase work is a cheap and efficient proposition compared with a 3-phase balancer. Where additional transformers are required, such as for the ribbon type of village, a single-phase system is cheaper and more easily handled as regards the line, switchgear, and transformer, and is quite as satisfactory as a 3-phase system for normal village work. The Aylesbury rural area consists of 230 square miles and is practically complete electrically. The population of the rural area is 44 000 (Aylesbury 13 000). The length of main 11 000-volt lines is 35 miles, and of other transmission and distribution lines is 167 miles. The bulk of the scheme was switched in by the end of 1926. The consumers in the rural area now total 4 692. The capital outlay on the rural scheme totalled £145 000 at the 31st March, 1931. The units sold were 4 795 000, and the revenue, including hire of wiring and apparatus, was £35 796. Included in these totals are the figures for one large consumer taking 2·5 million units for a revenue of £6 784. Although I hope for better times in rural areas, I wish to emphasize the necessity for covering all the ground at the least capital outlay. As the probable revenue is small, a profitable result can only be obtained by the use of steel-wire transmission and single-phase switchgear, transformers, and distribution.

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* The C.R.C. standard designs are the latest national at the present time.

(The authors' reply to this discussion will be published in a later Number of the *Journal.*)

WESTERN CENTRE, AT GLOUCESTER, 9TH NOVEMBER, 1931.

Mr. R. W. Biles: Any attempt to solve the problem of increasing the load upon our supply systems is very desirable in view of the necessity for reducing the supply charges to the consumer. One cannot help feeling, however, that some of the authors' suggestions, particularly those illustrated in Fig. 5, are rather extravagant. The diagram to which I refer shows that 64 132 000-volt grid points are necessary in an area of 25 600 square miles, or one grid point for every 10 miles square of area. From each grid point there branches off a radial 33 000-volt system to which a further distribution system operating at 11 000 volts is connected. One would have thought that at least one transformation could have been dispensed with in an area of 100 square miles, and that if the grid point had been brought to a central position the distribution from that point might have been carried out either at 33 000 volts, stepping down to 440 volts for the consumer, or, alternatively, at 11 000 volts. The possibility of carrying out rural electrification depends upon the load obtainable in the area, and the possibility of supplying cheap power depends upon the cost of distribution and interconnection; with present-day arrangements the scheme proposed in Fig. 5 does not appear to be a feasible proposition in any part of this country, at any rate at 132 000 volts. Until more economical arrangements of interconnection are available, there will be less chance of supplying power at the low rate that is necessary to obtain the business. The authors' remarks on the question of the earthing of transmission-line towers are of much interest. Although on page 214 they state that a cast-iron plate 18 in. × 18 in. × $\frac{3}{8}$ in. has almost by common consent been standardized, I think that cast-iron earth-pipes are being more universally used and are more satisfactory. It would be helpful if the authors could indicate the considerations which have led to the adoption of this type of plate or pipe. From tests which are now being conducted it appears that in many cases they might be dispensed with, especially on steel-tower lines, for it has been found that the resistance to earth of the tower is in many cases as low as, and sometimes lower than, that of the plate or pipe. In such instances the expense of putting in earth pipes is unnecessary. There appears to be little standardized information available on this subject, upon which some useful research work could be done in determining the limits of the current-carrying capacities of the various types of earthing devices.

Mr. W. Burton: I am in agreement with the authors regarding the essential points in the design of transformers. Reliability, low core loss, and low magnetizing current are all equally important. The question of close regulation is bound up with that of the mechanical strength of windings under short-circuit conditions, but since most rural transformers are at a considerable distance from the supply point, these forces are not likely to be exceedingly large. It is possible, therefore, for the designer of the transformer to arrange for closer regulation than would be possible if he had to place the unit very close to the power station busbars. The authors call attention to the possibility of using a core of decreased section run at a high flux density in order to keep down weight and loss. They rightly reject this solution on account of the high magnetizing current involved and the effect of harmonics in the system. Not only has a high magnetization current to be paid for in the kVA demand, but also, if the rural system has to be supplied through another transformer, this may have a high kVA load when not a single unit is being taken from the rural transformers. It is the practice of the company with which I am connected to limit the flux density to 12 000 lines per cm^2, and to require the magnetizing current to be not greater than 12 per cent in the smallest transformers and 5 per cent in large units. The authors appear to start off from the assumption that their rural scheme is supplied with constant voltage. If this is not the case, additional cost will be incurred in regulating at the point of supply. It would be interesting to know what is meant by "a design to B.S.S.171"; this is a guide to temperature-rise and overload capacity, but wide variations in all the design factors are possible within the limits of this specification. I am in agreement with the authors that fuses may be inserted on both the h.t. and the l.t. sides, but care should be taken to ensure that the rating of these fuses (especially on the l.t. side) bears some relation to the size of the unit.

Mr. J. M. Bowman: One omission from the Model Scheme is that no provision is made for lightning arrestors on the low-tension overhead system. Are the authors of the opinion that this type of protective device is unnecessary? In regard to the revenue to be derived from cottages in rural areas, I was always under the impression that people go to bed much earlier in the country than in the towns, and therefore in rural areas less use is probably made of artificial lighting. In my own undertaking the revenue per cottage is less than that given in the paper, and I therefore feel that the figure under this head is overestimated.

Mr. G. H. Bowden: The area considered by the authors is capable of intensive cultivation, and care will therefore have to be exercised by engineers who have to apply the data given in the paper to territory of which the topography differs much from that of the author's area, and which is not so completely agricultural. I do not consider that the domestic results of development work are as truly represented by a comparison between revenue and number of consumers as by a comparison between revenue and total earnings of the consumers of the district dealt with. The curve showing the relation between price per unit, number of units sold to consumers, and revenue obtained, interests me greatly. This experience of the many supply authorities from whose records this curve has been compiled should encourage those considering price reductions to go boldly forward. It is borne out by a story recently told me of a municipal engineer in the North of England who was requested by his committee to reduce the price per unit because, in the Council's opinion, he was making too much profit. He made a 25 per cent reduction in his tariff each year for 3 years, and at the end of the period the undertaking was making more profit than at the time when his Council complained. It is my opinion that in rural areas the tariff should be designed to encourage long-hour loads, for it is known that consumers who are subject to low voltage are far more apt to notice and complain of voltage variations than of a steady low voltage. Voltage regulators are expensive, and it appears to me to be economical to allow consumers to carry out what is in effect their own voltage regulation by following a tariff which encourages long-hour loads. It is surprising how debates on the price of electricity, which are common in cities and towns, are now extending to rural areas, and how unpopular high unit charges are with potential rural consumers.

Mr. W. A. H. Parker: The authors' revenue and expenditure account states that £520 would cover the cost of the whole of the publicity work in the sixth year of working of the Model Scheme. Surely this sum is insufficient to cover an adequate service to nearly 10 000 consumers, the cost of staffing showrooms, and general propaganda. I notice that the authors base all their estimates on revenue per consumer. Although it might be quite safe to use this basis for the scheme they have in mind, it would be dangerous to use their figures in order to obtain an idea of the revenue to be derived from a particular village or town, because of the large diversity of revenue per consumer which would actually be obtained. The following are the revenue figures on a 2-part tariff for our own undertaking.

Domestic Consumers.

Number of rooms in home	Annual revenue per room			Annual revenue per consumer		
	£	s.	d.	£	s.	d.
3	1	1	2	3	3	6
4	1	7	7	5	10	7
5	1	7	11	6	19	7
6	1	6	8	8	0	1
7	1	8	0	9	16	2
8	1	6	4	10	10	10
9	1	9	8	13	7	5
10	1	14	8	17	7	2
11	1	8	5	15	12	10
12	1	4	6	14	14	1

It will be seen that, whilst the revenue per consumer varies between £3 3s. 6d. and £17 7s. 5d., the revenue per room only varies between £1 1s. 2d. and £1 14s. 8d., which gives us a much better basis for the estimation of revenue, and we use this particular basis in connection with our own canvassing records. Turning to the question of the growth of connections, the authors estimate that 40 per cent of the occupied premises will be connected 12 months after the commencement of supply, and that at the end of 5 years practically 75 per cent will be connected. It may be of interest to give our own figures in this connection. Where gas was not available our best figure was 45 per cent connected during the first year (this was for a village connected last year), and, where gas was available, 20 per cent. We have not, however, been able to approach the estimated figures for the following years, and, apart from one or two small villages where the percentages are possibly higher, our best figure for the sixth year was about 50 per cent. I am of the opinion that the authors' estimates are reasonable ones, bearing in mind that the fullest use would be made of assisted wiring and an intensive publicity programme. In Table 19 the authors apparently do not take into account a large number of prospective, large cottage consumers who may be willing to use electricity for lighting only, and whose consumption would probably be from 75 to 100 units per annum. I suggest that good business could be done with this type of consumer on a slot-meter basis at, say, 8d. per unit, and in this way practically 100 per cent saturation would be achieved. My main criticism of the paper is in connection with the financial estimates. Although the authors are of the opinion that the hire and hire-purchase of apparatus and assisted wiring schemes are necessary for the rapid development of an area, no financial arrangements to cover these schemes are included in their statements of capital expenditure. Even if these schemes are to be self-supporting, those who would have to find the capital in the first instance should be told that further capital will be required. In order to emphasize my point I would refer to the amount of capital necessary for a cooker hiring scheme; approximately 10 000 cookers would be required in the sixth year, necessitating, at the low average cost of £10 each, another £100 000 of capital outlay. Further, my experience shows that the ordinary rentals of cookers do not adequately cover such items as interest, depreciation, obsolescence, maintenance, etc. The authors should therefore have included in their financial statements the necessary estimates of capital expenditure in these directions.

Mr. A. Ellis: It is stated in the paper that at a particular future period the cost of bulk supplies will be more uniform than hitherto, and that this may make the financial results of rural electrification more certain and render possible an extension of the radius of economical development. Unfortunately, however, there is as yet no indication of any substantial reduction in the cost of bulk supplies. A paper delivered at the 1931 Annual Convention of the Incorporated Municipal Electrical Association stated that the net result of the grid scheme would be an economy of approximately 0·05d. per unit, but we are hoping for better results than this. Although Table 3 shows a reduction in the units sold per £ of capital expended during a particular period, the reduction took effect during 1925–26, the year of the General Strike. Since then there has been considerable depression of trade throughout the country, which may account more than anything else for the reduction. The cost of distribution may also have been a contributory cause. It is interesting to see that in the authors' view an area not less than 400 square miles in extent should be considered for electrification, but unless in an area of this size there was some justification for the provision of a comprehensive scheme, it is difficult to imagine that either a company or a local-authority undertaker would risk the capital necessary and incidental to such a scheme, without being assured of an adequate return. In this connection I note that the authors have realized the difficulty of taking any known district as an actual example, and that they have merely attempted to formulate a scheme embracing average conditions. Table 7 shows that at the end of the year in question only 20 per cent of the available properties were being served; that of the total revenue obtained, 50 per cent was due to industrial supply, and that 80 per cent of the total units sold were used by factories. Further, that of the 2 485 farms served, the average revenue per farm was only £11, i.e. very little more than the cost to a consumer of ordinary domestic supplies. It is to be inferred from this that these farms are not using the supplies to any appreciable extent for agricultural purposes, a deduction which is rather supported by the figures (page 196) for the average revenue per consumer, viz. £15 7s. for the whole of Great Britain and £12 12s. for rural areas alone. It would seem that the only way of developing the use of electricity for agricultural purposes would necessitate the financing of the farmer by the supply authority, the cost of which would have to be taken into account. The success of a model scheme such as that prepared by the authors would be mainly, if not entirely, dependent upon the authorized undertaker being able to purchase supplies in bulk at a cost of £3 5s. per kW and 0·20d. per unit. It would be interesting to know whether supplies at a tariff of this sort are available in any district or are likely to become available. If not, the estimates will have to be adjusted to whatever tariff happens to be available, and consequently the results shown in the authors' estimates may have to be reversed. As regards the tariffs available at present, I have in mind a case where an authorized undertaker is purchasing supplies in bulk for an important borough from a joint electricity authority at the rate of £5 per kVA of demand per annum plus 0·5d. per unit. I am in agreement with the authors' statement that any drop in the charge per unit to consumers results in an increase of revenue, but any reduction in the charges for supplies to the ordinary consumer must to a large extent be dependent upon what might be termed "normal developments" occurring from time to time. I also agree that any increase in the quantity used should entitle the consumer to expect a lower charge per unit, a principle which, I think, prevails in general practice. Although the authors mention that under certain conditions of light load a galvanized-steel conductor might be considered in order to cheapen the cost, on page 213 they state that galvanized steel has a short life and little or no scrap value: consequently, one would hesitate to use it. Table 26, which gives the costs per head of population, does not take into account the cost of meters. The estimated cost of the scheme put forward by the authors amounts to £300 500 in the sixth year. Would either a company or a local-authority undertaker be able to raise the necessary capital for a scheme of this character, and in the case of a local-authority undertaker would such a scheme be authorized by the Commissioners, who would have to give their consent to the borrowing of the necessary capital? In the paper, interest on the capital is taken at 4·75 per cent and on the sinking fund at 3 per cent, which figures are somewhat lower than those usually prevailing. If the bulk-supply tariff had to be increased beyond £3 5s. and 0·2d., the profit of £11 035 shown for the sixth year would perhaps not appear at all. It must also be borne in mind that in a rural area, as in other more important areas, installations on consumers' premises would to a large extent have to be provided for by the undertaker. Whilst these are generally looked upon as forming a separate account, which would balance itself by the additional charges made in respect of supplies to repay the cost of the installation, the undertaker has to find the necessary capital with which to provide these installations at the outset, and has to depend upon the actual consumption of such supplies for determining the period at which the cost of the installation will have been repaid and the purchase money made available for the purpose of providing further installations. Finally, the paper states that, of the total rural area already covered by statutory powers, only 20 per cent has so far been supplied with electricity: is this due to the fact that the undertakers have realized that further developments will not give them an adequate return upon capital outlay?

Mr. H. S. Ellis: I have always maintained that, important as the grid may be, it cannot become fully effective without a comprehensive system of distribution between it and the consumer. I personally have had great difficulty in making up my mind as to how best to provide such a system in rural areas, and, unfortunately, I cannot reconcile many of the authors' estimates and figures with my own, which are based on actual practical experience over a number of years. We all know that the country dweller's desire to obtain electricity is more marked than that of the town dweller, but the problem is how to get it to his home "at a cost which will prove attractive" to him. The authors' figures of revenue to be derived from the consumers in their hypothetical area are, I presume, largely based on actual results, and they do not appear to be very different from what I have been accustomed to; nor have I any reason to criticize their scheme from a technical point of view. They appear to me, however, to have based their capital expenditure on the assumption that their lines are to be erected without meeting with the sort of obstacles that are encountered in a normal area, i.e. they have assumed that their system is to be established under ideal conditions such as are rarely, if ever, met with in actual practice, and that their materials are to be bought in bulk at prices much below those which have prevailed hitherto. Although (page 191) they "have realized the difficulty of taking for examination a known district as an actual example," they have not taken what might reasonably be considered an average district for this country. They have assumed as the nucleus of their rural scheme a large urban area; but I presume that they have not assumed that the rural scheme will be subsidized by the urban area. I mention this because I cannot conceive that the figures for expenditure on page 227—more particularly under "Management"—are sufficient. It would appear, for instance, that publicity is going to cost only £520 in the sixth year of development, when presumably the units sold amount to something not much less than the units purchased (19 638 000). Such an amount would not provide a single showroom or any sort of service in the area, i.e. it is assumed that in the sixth year and afterwards there is to be no sales department. According to my own experience the amounts they have allowed under distribution costs would hardly provide the necessary amount of transport for the undertaking's maintenance staff, not to mention materials and workmen's wages. The maintenance of services and the bringing in and testing of meters (bearing in mind that meters ought to be tested and recalibrated, say, once in every 5 years) for 9 746 consumers would, I submit, represent a fairly considerable item of expenditure, such as, I think, cannot have been included in the authors' revenue and expenditure accounts.

Mr. W. Hill: The authors' costs of overhead lines provide for two road crossings per mile, and no reference is made to the protection required at the crossings of Post Office lines or railways on any of the e.h.t. lines. Both of these types of crossings are considerably more expensive than road crossings, and in our area we get one of each of these per mile. I am also surprised to note that no earth wires are to be erected. If it is possible to obtain good earths easily, it may be cheaper to omit the earth wire, although it acts as a guard wire and is one of the best protections against lightning. Trouble was experienced in Gloucestershire, where an earth wire was omitted. I am pleased to see a reference to concrete poles, but if they are economical it is surprising that they are not being used at all in either Bedfordshire or Norfolk. I am rather surprised that the authors advocate a small size of steel-cored aluminium conductor and make no reference to cadmium copper, which we have found to be very economical. With regard to voltage variation, it appears from the authors' figures that there will be a variation of 12 per cent at consumers' terminals after allowing for the two transformers and the h.t. and l.t. lines. I note that there will be no period of light load, as water-heating will be undertaken during the night, but, if the variation is not to be excessive, the minimum load will have to be 50 per cent of the peak. I do not think that one can hope to approach this figure, as it would apply to each individual l.t. network.

Mr. F. H. Corson: As my area of rural supply is much smaller than that considered in the paper, I propose to refer to a few of the more general aspects of the question. The solvency of the whole scheme seems to rest upon the purchase in quantity of standardized materials of construction and upon the availability of bulk supply at prices such as those set out in the paper. These, however, are much lower than the generally prevailing prices. I am not at all sure that the advent of electricity supply into the country districts would be as important a factor in the movement of industry from town to country as the authors suggest. De-rating legislation has removed one of the main disadvantages of urban sites, and in regard to such matters as housing, education, amusement, transport, medical attendance, etc., the establishment of industry in rural districts presents many difficulties. I should have liked to have seen in the paper some reference to protective measures for ensuring localization of electrical disturbances on the system. The authors appear to rely solely upon fuses, and to take their supplies from the nearest available point; under these conditions disturbances might have very widespread effects. I am in agreement with them as to the necessity of 2-part tariffs, although, in view of the growing popularity of prepayment metering, such tariffs are not always easy to arrange. Further, if restricted-hour demands (e.g. for water-heating) are to be dealt with, time switches providing for a third rate in the tariff may be necessary. If these devices are fitted, the authors' figure of £2 for meters may be inadequate, and for these reasons I do not agree with their proposals to abolish meter rents. I think that they have underestimated the charges for rent, rates, taxes, etc., as in my rural district the charges for rates alone are considerably higher than the sum allowed for the whole of this item of expenditure. Finally, as to the question of cables versus overhead lines in village distribution, I would emphasize that the difference in cost should be considered not as a separate item but rather in relation to the whole capital expenditure. In some cases the extra expense of providing cables has a comparatively small effect upon the cost of supply, and if the subject were regarded in correct perspective we might less frequently have to lament injury to the beauty of many of our villages.

Mr. G. D. Coe: Referring to the size of conductors proposed for low-tension distribution under the Model Scheme, in no case would I put up a distribution line of less than 0·05 sq. in. cross-section, whether for single-phase, or 3-phase 4-wire, supply. The electricity undertakers in rural areas must cater for electric cookers. I have in mind a small village in Herefordshire with only 23 consumers, more than half of whom have electric cookers installed; conductors of No. 8 S.W.G. would be useless for such a purpose. What I desire to stress, and what in my opinion the authors do not sufficiently emphasize, is the absolute necessity of a deferred-payment wiring scheme being in operation throughout the area of supply. As an example of this, I would refer to another village in Herefordshire where an electricity supply from a public source has been available since 1922. During the first 7 years, only 44 (i.e. one-half) of the dwelling-houses in the village were wired and connected to the supply. After a deferred-payment wiring scheme had been in operation for some 18 months to 2 years, the number of consumers was doubled and before the end of the present year every dwelling in the village, including the church and local lock-up, will be connected to the supply. I should be glad to have the authors' suggestions for dealing with isolated supplies to farms, country residences, and hamlets, as this is one of the most difficult problems met with in a rural area such as Herefordshire, where the density of the population is only approximately 65 to the square mile, excluding the few urban districts. The authors have suggested that these extensions might be carried out with the help of guarantees, but from my experience in Herefordshire I am loath to agree with this suggestion, as in practice I have found it exceedingly difficult to operate. Were the electricity undertaker in an area such as the 800 square miles of Herefordshire to connect up these isolated supplies free of cost to the consumer, as might be inferred from the Model Scheme, the cost would be colossal in comparison with the revenue to be obtained. I have so far been unable to solve this problem except where the isolated supply is to a large residence or to a number of large houses, where the consumption and consequent revenue would warrant a spur line.

(The authors' reply to this discussion will be published later.)

SCOTTISH CENTRE, AT GLASGOW, 10TH NOVEMBER, 1931.

Mr. D. M. Macleod: I am sorry to note from page 193 that the authors have not given some of the information in relation to Scotland which might have been expected. Fig. 1 indicates the position in Scotland fairly well, as it shows a large percentage of hilly country with the population confined to a restricted area. This condition is met with throughout the Highlands of Scotland. Many of the Continental countries have of recent years been developing their water-power resources with great success, and while Scotland cannot boast of a very large population, it has, on the other hand, extensive supplies of water power which are well worthy of further development. This view, I think, ought to be taken into consideration by the Electricity Commissioners in connection with Scottish rural-development schemes. If we were to regard Scotland purely from the population standpoint, rural development would appear to be hopeless from a revenue-earning point of view. Taking into account the lochs situated at high altitudes, however, there are a number of instances where water power could be usefully developed through the agency of automatic hydro-electric plants. If these places are to look for an extension of the "grid" supply, they may have to wait a very long time before anything eventuates. Take, for example, the countryside in Mid-Argyllshire. There we have hill lochs, situated some 600 ft. above sea-level. These are now used simply as feeds to the Crinan Canal. There could be no serious engineering difficulty in making that water power perform the useful function of generating electrical energy for the benefit of adjoining towns, and conceivably the development of such a scheme would lead in the course of a few years to a junction with the grid supply. During the process of such development the water-power scheme would, I believe, be self-supporting. I agree with the authors that there is a great need for the simplification of tariffs. It is the experience locally that when a reasonable and readily-understood tariff becomes available, the supply automatically and rapidly develops. Imagine the complication arising from, say, a railway company charging passenger fares on the basis of weight and distance; yet that would be a perfectly logical thing to do. In my view, supply authorities should take an average of their prices and be in a position to quote rates and tariffs that can be readily understood by the man in the street. As regards design, there is a certain satisfaction to engineers in this district to find that the system favoured by the authors—namely 11 000-volt 3-phase transmission, and 400/230-volt distribution—has been used on the Clydeside with unqualified success during the past 25 years. I note that the use of reinforced-concrete poles is suggested, and I think that there is a future for these. One of their great merits is that they can be manufactured at site, and thus transport and handling charges can be saved. Further, their maintenance cost is practically nil and their life indefinite. Coming to the constructional details given in the paper, I am not altogether enamoured of some of the designs suggested for high-tension lines; for example, those shown on page 219. These would not be proof against the attacks of birds.

Mr. E. Seddon: At the top of page 190 the authors state that electricity will shortly be available from the grid at a reasonable price to all authorized undertakers. I should like to know how this will be effected, because it seems to me that even a small town could hardly afford to stand the capital charges involved in tapping the lines. Perhaps the authors have in mind the possibility of being able to use small transformers connected direct through suitable fuses to the grid lines. Lower down on the same page reference is made to the decrease in consumption per £ of capital spent on distribution. This is apparently due to the majority of undertakers having to go further afield for load than formerly, as it is obviously more economical, as regards distribution, to supply consumers near to the generating station than those many miles away. On the other hand, there must be many authorities who can show surprising results the other way. In Edinburgh the units sold per £ of distribution capital for the first and last years shown in Table 3 are respectively 45 and 75. I am quite in agreement with the reference to tariffs on page 205, where it is stated that the time has come when little or no check should be placed upon the use of electricity by the kinds of restrictions at present imposed by reason of load factor or time of use. I believe it is better to make the running charge low enough to enable one to use electricity for room heating and water heating without reference to time of use. In the undertaking in which I am interested a certain number of units is allocated for lighting, then all units above this figure are charged at $\frac{5}{8}$d. until 10 times the lighting allocation is reached, when the running charge becomes $\frac{1}{2}$d. per unit. In extending the supply to villages around a large city, it is, I think, the best policy to put all mains underground. With the expansion of the city the villagers of to-day become merged in the urban population of to-morrow, and an engineer who boldly goes forward with an underground scheme will be thankful in the future for having done the right thing from the start. The Edinburgh Corporation are at present supplying 17 farms, one or two being approximately 10 miles away from the generating station. The average revenue per farm amounts to £18 per annum, with a consumption of 3 230 units, or an average price of 1·345d. per unit. In addition to these, one large poultry farm situated 7½ miles away from the generating station consumes nearly 1 000 000 units per annum.

Mr. D. H. Bishop: There are one or two points on which I should like information. The first relates to the statement on page 202, that the authors have examined the returns of 221 authorized undertakers who operate in rural areas. Do these undertakings only deal with rural areas, and do they have no urban areas combined with them? My reason for asking this is that it is deduced from their examination that the average price received from the rural areas is rather less than that received from the other undertakers, who operate, I suppose, in urban areas. I feel that perhaps the reason is that the undertaker cannot get any more from the rural areas, and so manages somehow to extract the extra money from the urban areas. The other point relates to the curves of price and units per consumer. It is very interesting to find that the points lie so consistently on a line. Although this is probably as good a guide as any, I do not think that it should be used without carefully considering all the factors that enter into the question. For instance, these points record the results of undertakings which are already working, probably under the conditions that the authors describe on page 193 when they state that development is proceeding on the line of least resistance. This means that those areas which seemed to be the easiest ones to develop economically have been developed, and I therefore feel that a little caution should be used in applying these curves for forecasting future results, when areas which will be more expensive to develop will be supplied. Caution ought to be used in applying the results to any particular area. Supposing there are two areas, one highly industrialized in which the industries are largely running 24 hours per day, and another one where the hours are limited to, say, 50 per week. The number of units per consumer may be the same, but it is very much cheaper to supply a given number of units per consumer in the former areas where the industries work 24 hours per day, than in the latter where this number has to be supplied during 50 hours in the week. In a general survey such as the authors have made, such considerations, of course, cannot be taken into account. One other point is that for one of their curves the authors have calculated the cost of cable with a 7 per cent variation in voltage. I should be very glad if we could depend upon this figure, but we find that the out-of-balance load on the 3-phase 4-wire system upsets the calculation altogether.

Mr. H. C. Babb: In their Model Scheme the authors have only followed the practice that has been established in Scotland for many years, and which my company have been carrying out for the last 7 years. The particular point that strikes me is the amount of revenue obtained from domestic consumers, which, according to the Model Scheme, is 4·9d. I find that we get only 2·97d. Of course in rural electrification it is not so much the cost of the current as the cost of distribution which is important. I am sorry to say that I cannot get my figures for the erection of overhead lines down to anything like the cost given in the paper. In Mr. Macleod's supply area there is a denser population, and he probably can afford to spend more money upon the erection of lines than one can where there is a sparse population. As regards putting up single poles close together without stiffeners, a severe storm of the kind met with in Scotland would soon blow them down. The majority of the overhead-line engineer's troubles are due to lightning. Lightning troubles, I am convinced, are greatly reduced if an earth wire is used on the top of the lines. None of the lines shown by the authors has provision for such a wire. I am sure that my own system will not compare favourably with the Model Scheme, because the population in the area is nothing like so dense as that indicated in the paper. I think that the same is true of the greater part of Scotland, with the probable exception of the Clyde valley.

Mr. W. J. Cooper: The authors give figures showing a lower average price per unit to the consumers in rural than in urban areas. Are these rural areas supplied from an established urban-area undertaking? If so, it would appear—as Mr. Bishop has suggested—that the average price obtained in the rural area is the maximum that can be obtained and that it is only possible when the rural area can be helped out by the more profitable urban area. I am glad that the authors have laid stress on the need for dealing with rural electrification in the largest area possible. The whole question of "cheap and abundant" supply is bound up with wide-area distribution in order to obtain the fullest advantage from diversity of use. In this connection, I hope that some authority or institution will make itself responsible for ascertaining what degree of diversity does exist, so that ascertainable costs may be modified by a suitable constant dealing with diversity, for the purpose of tariff-building. Only if this is done can undertakings adopt low tariffs with confidence. The adoption of attractive low tariffs may, however, be a matter of speculative courage, founded on a belief in the fundamental nature of the need for electricity supply rather than a question of figures. Many of the tariffs now quoted lead to the same average price per unit, and something could be done now towards the adoption of a uniform form of tariff easily understood by the consumer. The public will pay what is required for electricity supply when it recognizes that electricity supply is essential to its well-being. A person who now pays £25 per annum for tax and insurance on a motor-car, objects to £5 as a service charge for a supply. The authors have several times referred to the fact that the lowering of prices increases revenue, but really there is nothing new in this contention. There is a successful undertaking of another nature which realizes that although there is a limited demand for pots and pans at 2s. 6d. each, there is a very much greater demand and a much increased revenue if these articles are sold at 6d. for the pot and 6d. for the lid.

Lieut.-Commander L. R. D. Helm (*communicated*): The authors call attention to the advantage of using light copper conductors instead of the 7/12 S.W.G. steel ones now in vogue. A good example of such lines is found in the Irish Free State Shannon scheme, which follows Continental design and practice. Three-phase 10-kV lines with seven-stranded 10- or 16-mm^2 copper conductors are used for branch lines supplying pole-mounted transformers feeding into the low-tension pole networks of small country towns and villages. A poles with special foundation brace blocks, obviating the use of stays, are placed at all heavy angle or terminating positions. Single wooden intermediate poles carry the conductors in triangular formation on simple, bent cross-arms of channel section, which are secured to the pole by coach screws. Straining insulators are not required for angle positions, or termination, because double pin-type insulators are sufficiently strong for these light lines. Further economy is obtained by using painted instead of galvanized ironwork, and by despatching the insulators with rigidly-attached spindles to the place of erection in special wooden crates, which can be conveniently handled. Experience shows that galvanized-steel earth-wires often break quite unexpectedly in bad weather. In the event of a steel conductor breaking and causing a fatal accident, the cost of compensation and loss of public confidence would outweigh any economy in initial expenditure. Steel lines, where long spans are used, cannot be constructed cheaply where hedge lines have to be followed as a concession for the granting of wayleaves. It is suggested that light, copper lines are admirably suited for the purpose where this difficulty arises.

(The authors' reply to this discussion will be published later.)

SHEFFIELD SUB-CENTRE, AT SHEFFIELD, 18TH NOVEMBER, 1931.

Mr. S. R. Siviour: The importance of this subject is shown in Table 1, which indicates a gradually increasing percentage of the total cost of energy attributable to distribution. Table 2, showing a steady fall in the cost per unit sold, is a good reply to public criticism regarding the cost of supply. The authors' reference to statutory enactments calls to mind the fact that there is scope for lightening the burden of undertakers in certain respects. We are still threatened by divers penalties contained in eight principal Acts and at least a dozen others dealing with factories, mines, telegraphs, roads, bridges, public health, and the like, not to mention numerous special Acts, Orders, and statutory regulations; in fact, the engineer administering the distribution side spends much of his time on purely legal matters. Many of the present statutory provisions, including regulations, do not cater for modern conditions and the evolution of the technical element. Our powers for breaking up streets are primarily based on an Act of 1847, and some of the regulations for securing the safety of the public are not only out of date but also require clarifying in respect of similar requirements in the Factory Regulations. What we need is a codifying Act which will simplify the statutory requirements: similarly all regulations should be brought into line with modern practice, and overlapping and ambiguity should be removed. This would result in a reduction in administrative time and a speeding-up of the process of giving supplies. The Model Scheme does not provide for supplies for public street lighting, although my experience is that country villages want this service and consider it to be a useful addition to their amenities. It should be remembered that with a 100-watt lamp (a 150-watt lamp is better and is now commonly adopted) the consumption is at least equal to that of the small cottage where only lighting is taken. The addition of a switch wire, lamp fitting, and time switch, involves quite a reasonable cost and the supply is profitable, particularly if the parish council undertakes maintenance and renewals. While I agree with the authors' choice of a hypothetical area for their scheme, I think they will admit that as regards capital expenditure, operation, and development, a scheme carried out *de novo* has a great advantage over one carried out under individual orders. There can be no question that overhead lines are essential in rural schemes, and the need for economy is clearly shown on page 192, where it is stated that 92 per cent of the total area of Great Britain contains only 22 per cent of the population. In spite of claims that underground cables can be justified for rural work, investigation shows that even where the conditions are exceptional it is only being partially applied. The recent pronouncement by the Electricity Commissioners to the effect that an analysis of undertakers' returns showed that underground work costs twice as much as overhead lines, indicates clearly that the former cannot generally be an economic proposition. At the same time, I do not see how the authors can ignore some provision for l.t. cable distribution in their Model Scheme. Some villages are so thickly wooded as to prevent one from erecting overhead lines without risking being accused of vandalism, others have property built right up to the frontage, thus preventing proper clearances, or G.P.O. wires may occupy the desired position; one would be very lucky to be able to adopt a 100 per cent overhead system. The need for suitable and attractive tariffs and facilities for wiring and hire purchase cannot be too strongly emphasized. The distribution engineer wants nothing so much as an improved load factor on the mains. As regards the authors' reference to the sporadic nature of much rural distribution, I must put in a plea for Yorkshire, where, in addition to many mixed semi-urban and rural districts, one particularly rural district of over 100 square miles bears comparison with the Model Scheme. This area has a population density of 144 persons per square mile and contains no potential power other than the usual small-power machinery associated with town or village life. Networks have been laid down in 22 villages, and 20 other isolated supplies have been given. The length of l.t. mains per village amounts to nearly 2 miles, and by the end of the fourth year of working approximately 45 per cent of the total number of premises had been connected. With regard to Fig. 4, the estimate of growth is unduly optimistic, even allowing for intensive propaganda. The ability to pay—both for the supply and for installation—is an important factor, especially at times when unstable employment conditions obtain. Further, the villages contain a large proportion of the smallest type of property. As regards Fig. 5, I suggest that there are rural areas yet to be developed which are remote from the "grid" or from undertakers' lines, and extensive 33- or 66-kV lines will be necessary in such cases. Fig. 7 shows an estimated improvement in load factor of from 12 to 23½ per cent (approximately) by the end of the sixth year. Presumably this is based on a fair proportion of industrial load, as it is noted on page 207 that an allowance of 50 per cent has been made for this. I have already cited a concrete case where no industrial load exists, and I think that the assumed increase in load factor will not be borne out in many areas. In Table 24, 0·02-sq. in. (No. 8 S.W.G.) conductors are included. I doubt the wisdom of using such a small-capacity wire, as sooner or later the inevitable 10-kW consumer will appear on the extreme end of the line! The advantage of an 11-kV system has been abundantly proved, and as regards switchgear many manufacturers now offer 11-kV apparatus for 6-kV working in order to reduce types, so that there is no case for the lower voltage. I do not share the authors' views that long spans are at a disadvantage in undulating country, as from an examination of records relating to transmission lines of 150 miles route length where long spans are used, the variation in span lengths is found to be from 5 to 10 per cent. The secret is, of course, careful surveying and plotting of support positions to suit the ground contour. The reduction in the number of insulators makes long spans well worth while. As regards insulators, I believe in having a good margin, but care must be exercised to co-ordinate the insulation over the whole system, otherwise troubles with terminal apparatus are increased. With regard to Fig. 18, I consider all forms of bird guards or perches to be wholly unnecessary and a waste of money, as they very often increase maintenance costs and introduce other troubles. The solution is to be found in the use of a sloping bracket—on the lines of Figs. 20, 21, and 22—but the last-mentioned is not good in the matter of clearances. The horizontal-base triangle arrangement shown in Fig. 19 is simple and cheap, but it is only satisfactory if the clearances are sufficient to avoid clashing due to non-synchronous swinging. The tipped triangle has much to commend it, although it is perhaps a little more costly. Steel lines may be justified for small loads in a clean atmosphere, but their life is short in this part of the country. I am surprised that the authors do not suggest a single-phase system for some of the spur lines and isolated supplies. Although the saving on conductors is small, such a system introduces an economy in transformers and switchgear, and involves no difficulty in balancing the main circuit. Not only is a single-phase arrangement suitable on the high-voltage side, but also in the case of very small villages where the power load is small there is much to be said both for single-phase working and for a single-phase 3-wire system using a transformer with 460-volt secondary and the mid-point earthed to give the standard voltage of 230 volts. This 3-wire single-phase system gives four times the capacity of a straight single-phase 230-volt supply and can be converted to 3-phase 4-wire by the addition of one conductor and a change of transformer. Single-phase motors present no difficulty to-day, and any motor over, say, 5 h.p. might be connected across the outers. With regard to pole equipments, I would emphasize the need for providing for safety in operation and maintenance—often carried out under adverse weather conditions. In particular, l.t. and h.t. circuits should be well separated; a small cabinet at ground-level is very convenient for the l.t. control gear. Fuses on transformers up to 100 kVA have been found quite satisfactory. The curve of Fig. 30 is interesting, and confirms my experience that 0·10 sq. in. is an economic size for l.t. overhead work. Copper is the most suitable conductor material for l.t. distribution, and it avoids the troubles attendant on bi-metallic contacts at connecting and tapping points. The average cost of services is given as £2: this is much too low, and the figure should be at least doubled. I should like to know whether the authors have allowed for earthing arrangements for the service equipments, bearing in mind that in many rural districts there is no water-main system. As regards capital expenditure, while I am not in a position to dispute the 11-kV line costs, I think that they must be net contract prices. They do not appear to include any addition for undertaker's supervision and establishment charges, which are of some consequence when it is remembered that construction is scheduled to take place over a period of two years. It is also not clear whether allowance has been made for railway, power-line, and G.P.O. crossings, or compensation for damage to crops and trees. As regards revenue, I think the increase in units sold per consumer is unduly optimistic and is not borne out by general experience. On the other hand, the decrease in the price per unit sold over the same period points to a rather generous tariff, and there is room for adjustment here to offset the excessive consumption allowed in the later years. In their capital charges the authors provide for a uniform life of 20 years on the whole plant, whereas the Central Electricity Board allow 25 years for overhead lines, 40 years for cables, and 20 years for plant, with a rate of accumulation by interest of the sinking fund at $4\frac{1}{2}$ per cent, as against the $3\frac{1}{2}$ per cent suggested in the paper.

(The authors' reply to this discussion will be published later.)

MERSEY AND NORTH WALES (LIVERPOOL) CENTRE, AT LIVERPOOL, 7TH DECEMBER, 1931.

Mr. S. E. Britton: I am afraid that the authors' zeal for detail, shown by the 47 pages of the paper, may frighten off some engineers and supply authorities who ought to be encouraged to embark upon a scheme of rural electrification. Apart from the detailed explanation of matters with which rural electrification is involved, the paper appears to be written around what the authors call a "Model Scheme," based upon information collected by the Electricity Commissioners from some 220 undertakings supplying electricity in rural areas. I do not attach much importance to the Model Scheme, because there are few, if any, "model" areas in the British Isles. If there happen to be a few so-called model areas, I fear that the authorities which supply them will not regard them as such, and they will have little difficulty in showing that it is impracticable to develop their areas, as the financial results would be so poor compared with those given for the Model Scheme. The same applies to undertakers whose districts include undeveloped areas which do not conform to the authors' specification of a model area. I understand that the conclusions the authors have come to must not be regarded as the views of the Electricity Commissioners. I hope this is correct, as one of the authors' fundamental conclusions regarding successful rural electrification is at variance with decisions come to by the Electricity Commissioners when considering applications for Special Orders covering rural areas. I propose to confine my remarks to the 13 conclusions which appear on pages 234 and 235. (1), (2), (3), (4), and (5) are really matters of fact, within the limits of accuracy of the information upon which they are based. I regard (6) to (13) as real conclusions, and I find it convenient to deal with them in the following order:—(9), (10), (12), (13), (11), (8), (7), and (6). (9) really contains two conclusions:—(*a*) The scheme should be designed well ahead of present requirements; (*b*) the area of supply should be greater than 400 square miles. If any importance is attached to putting these two together, I consider it important to add a third, namely conclusion (10), that the best pressure for h.t. distribution is 11 000 volts. While I agree with the authors' choice of voltage, I disagree with conclusions (*a*) and (*b*). I am of opinion that in practice the size and development of an area cannot be settled on the basis of a hypothetical model scheme. If 11 000 volts is accepted, the size of a particular area will mainly be governed by (i) the locality of the source of supply, (ii) the maximum quantity of electricity the potential consumers may reasonably be expected to consume, and (iii) the quantity of electricity that can be economically supplied by the most economically constructed high-tension line, not overlooking possible demands which may arise from the development of untapped natural resources. There is no justification for stating that the size of an area should be 400 square miles, or any other figure. Areas should, however, be as large as possible, so as to give the most economical results in capital expenditure, administration, service to consumers, and reliability of supply. It may be that there are instances where 200 square miles is the most economical area, and there may be other cases where the potential use of electricity is so small that the area may be substantially in excess of 400 square miles. Apart from technical considerations, I am opposed to the granting of statutory powers to any local authority, company, or person, not already possessing an established undertaking in an urban area which is supplying electricity for all purposes at rates which make it practicable and economical for general use. I do not believe there is a rural district in this country which comes within the limits of 11 000-volt transmission, that can be supplied at prices to enable electricity to be used for all the purposes to which it can be economically applied in urban areas, unless the area is supplied by a successfully-operated established undertaking. From the Special Orders granted in the past it appears as if the Commissioners had a desire to publish at the earliest possible moment a map of England, Scotland, and Wales, showing the whole of the area allocated to statutory undertakings without due regard to the possibility of giving a proper and low-priced supply. Special Orders have been granted to authorities which cannot afford a competent staff, an effective showroom, adequate service to consumers, or be expected to display the sort of enterprise necessary for successful rural electrification. In my opinion the distribution powers of such authorities should be cancelled and the whole country re-arranged so that every distribution area is associated with an established urban undertaking, equipped with all the resources that are required to supply electricity at commercial rates, and able to give the service essential if the utmost is to be got out of electricity for the benefit of the consumers and the country generally. It would be unwise to accept without qualification the proposal to develop a rural area well ahead of the requirements. Under present conditions it is difficult to make rural electrification pay, but if a rural area is attached to an established urban undertaking more rapid expenditure of capital is possible, and although the revenue obtained may not be sufficient to meet the liabilities of a purely rural scheme, when the latter is merged into an established undertaking the necessary support can be obtained without embarrassing the undertaking as a whole. I have learned by experience that the inhabitants of neighbouring villages have entirely different outlooks in regard to electricity supply. In one case the majority of the possible consumers may be obtained and they may develop the electrical habit quickly, whilst a neighbouring village may stand aloof for a number of years. Such actual experience has taught me to be cautious about providing on too large a scale for future requirements. Referring to conclusion (12), I agree with the general statement that there is no apparent reason why authorities should not develop their rural areas. As statistics show that the average population of rural areas is 160 per square mile, I think that electrification should not proceed indiscriminately throughout the whole area, but should only be carried out when there are potential consumers so located as to enable the supply to be given on a commercial basis. I cannot support the opinion (conclusion 13) that goodwill and co-operation can enable electrification to proceed in areas with a population of a little over 75 per square mile, unless this meagre population consists of wealthy people. I do not place much importance on the population per square mile. What is important is the number of consumers that can be obtained per mile of line and their ability to buy electricity, i.e. the number and class of consumers that can be obtained by a definite expenditure. Where an annual income of £40 per consumer is forthcoming it is possible to supply from a high-tension steel-wire line, including a 10-kVA transformer, isolated consumers at an average distance of half a mile apart. Experience has taught me that most country folk are willing to spend on electricity an amount equal to upwards of half the net annual value of the premises they occupy, the exact amount depending on the extent of their wealth and their desire for comfort. Although a good deal has recently been said regarding the standardization of materials used for overhead lines (conclusion 11), in practice little saving would result from standardization. If, for example, it were decided to use for conductors only copper, aluminium, or steel to an equivalent copper section, it would have little effect in the direction of cheapening the cost of conductors. Fixing the distance between poles would probably increase the cost of imported wooden poles, as everybody would want practically the same size of tree. Similar remarks apply to insulators and means of support. While I am in favour of courage and optimism when considering tariffs (conclusion 8), these must conform to conditions which ensure an amount of revenue bearing some relation to the capital expenditure. What is meant by "a tariff in which the charge for electricy is reduced *pro rata*"? Does this mean a 2-part tariff under which the greater the quantity of electricity used, the lower becomes the average price per unit? I favour a tariff which consumers can understand, which encourages the use of electricity for every practicable purpose, and which enables the undertaking to pay its way. Until electricity can be supplied at a flat rate of, say, ½d. per unit for all purposes, a 2-part tariff with the fixed charge as high as possible and the unit charge as low as possible, is essential. Despite all the faults of the rateable-value method of computing the fixed charge, I have yet to be satisfied that there is a more expedient basis. I agree with conclusion (7), provided domestic and industrial conditions are normal. I do not support conclusion (6), that co-operation between authorized undertakers, manufacturers, contractors, and the Central Electricity Board, is essential for the solution of the problem of rural electrification. Why are the Electricity Commissioners omitted from this list? I prefer to suggest that greater good would arise from co-operation between authorized undertakers, consumers, owners of property, and local councils. What is urgently wanted, however, is the co-operation of the electricity supply undertakings in the work of re-allocating the whole of the country to authorized undertakers possessing sufficient resources and willing to provide the largest possible areas which can be economically dealt with at 11 000 volts. (Mr. Britton here exhibited a number of lantern slides.) With regard to the cost of overhead lines and substations, high-tension lines—including surveying, tree-cutting, and compensation—have been put up in the Chester area at £717 per mile for 0·1-sq in., £576 per mile for 0·075-sq. in., £552 for 0·05-sq. in., and £404 for 0·035-sq. in. cross-section. The average cost of 86 miles of No. 1 S.W.G. wire low-tension lines was £679 per mile and the lowest figure was £555 per mile. In the village of Aldford, where the lines are placed behind the houses, the cost was £585 per mile. I am now using reinforced-concrete poles for 3-wire h.t. lines costing less than £350 per mile with 0·025-sq. in. steel-cored aluminium conductors, and for £500-per-mile low-tension lines carrying four No. 1 S.W.G. solid copper conductors. I would abolish the use of double insulators at road crossings, and would in this country omit ice loading from the calculation of the factor of safety. I would allow low-tension lines to be erected along the roadsides with a clearance of 15 ft., and when placed in hedgerows—on supplies to farms and other isolated consumers—12 ft. I would also allow a 10 per cent voltage-drop. I have not found it necessary to install lightning arrestors, and I prefer earth-plates to an earth conductor run from pole to pole. The following figures show the sort of progress that can be expected in a village. They refer to four different villages [(*a*), (*b*), (*c*), and (*d*)], two of which have had a supply for 7 years. In (*a*) the number of occupied premises was 66, there were 6·2 miles of road in the parish, and 2·5 miles of electric lines were erected. In the first year, 44 consumers were connected and the average figure of units consumed was 106; at the end of 7 years there were 49 consumers and the average figure of units consumed was 802. (*b*) Number of occupied premises 239, 6·5 miles of road, 4·33 miles of low-tension line; in the first year, 42 consumers; at the end of 7 years 155 consumers; average consumptions 207 and 407 units respectively. (*c*) 6 years of supply; first year 58 consumers, average consumption 247 units; sixth year 190 consumers; average consumption 1 256 units. (*d*) 4 years of supply; first year, 18 connected, average consumption 305 units; fourth year, 27 connected, average consumption 765 units. I think that rural electrification is one of the best things the Electricity Commissioners have attempted, and they have not done it well. I know of no class of consumer who appreciates electricity more than the country dweller, and no class are more willing to pay as much as they can afford for a supply.

Mr. J. Scott: I should like to know whether the paper is based on information extracted from the results of undertakings in existence at present, and whether these results have been obtained by the extensive use of domestic apparatus; because, if so, why have the authors made no provision for capital expenditure on such apparatus? The results given in Table 11 are in my opinion reliable, and my own experience of a number of undertakings leads me to believe that much better results could be obtained if engineers would adopt the bold policy of selling energy for heating, cooking, and power purposes at the flat rate of 1d. per unit. This, of course, would have to be supported by a scheme of free wiring, free installation, and maintenance of domestic apparatus at nominal rentals. One of my undertakings, which serves a purely residential district where there is no industrial power, shows the following results at the end of the sixth year of working. It has a load factor of 25 per cent, and 63 per cent of the premises are connected to the supply, this in face of a serious gas competition. The average revenue is 2·445d. per unit, or £7 9s. per consumer per annum. The total losses amount to 9 per cent. Street lighting is automatically controlled by a fifth wire, and the district is completely lighted by electricity at a rental of £2 10s. per 100-watt lamp per annum. There are approximately 250 free-wired premises, which are charged at ½d. per unit above the flat rate. The undertaking purchases its energy in bulk at £8 per kW plus ½d. per unit. The rural scheme described by Mr. Britton operates in an area which a large undertaking refused to develop only a few years ago. By the end of the third year's working the following results had been obtained:—load factor 33·9 per cent, average revenue 2·5d. per unit or £9·2 per consumer per annum, 35 per cent of the total number of premises connected, average consumption 840 units per consumer per annum. The whole of the street lighting is done by electricity at a charge of £2 10s. per annum per lamp. The number of units purchased was 830 000 during the third year. The bulk supply is purchased at £7 per kW plus ½d. per unit. Another undertaking which has just completed its first year's working in a rural area has 625 consumers connected, which represents approximately 70 per cent of the premises in the area supplied; 260 premises were wired free, their occupiers paying 1d. per unit extra for lighting. The undertaking attained a load factor of 18·6 per cent; there are 160 cookers, 110 radiators, and 11 wash-boilers on hire. The street lighting is all electrical, controlled by a fifth wire. The system is purely underground, and the bulk supply is purchased at £6 per kW plus 0·3d. per unit. I do not agree with the authors' suggestion on page 205 that no check should be placed upon the use of electricity. I should like them to know that I have just completed two other townships where I have laid 6-core underground cables. The fifth core is for automatically controlling street lighting, and the sixth core is for the purpose of giving off-peak loads for domestic water-heating and process work in mills. Neither of the undertakings has completed its first year's working, but there is every indication that they will attain a load factor of 35 per cent. A 50 per cent load factor should be easily attained by such a scheme under proper management. Whatever may be the criticisms of the working costs shown in the paper, I am convinced that the authors' load factors are far too low. Much better results will easily be obtained. I am surprised that no provision is made for public lighting, as I have never experienced any difficulty in persuading parish, rural, or county councils to adopt a system of public lighting such as those to which I have referred. Mr. Britton believes that it is an advantage for the low-tension network to be erected at the back of the house. I do not agree with such a suggestion, simply because it precludes the possibility of giving a cheap public-lighting supply. A speaker criticized the losses allowed by the authors, and stated that the figure of 20 per cent would be more correct for the low-tension network. If this is based on his single-phase system, I am not surprised that such results are obtained. I cannot imagine any efficient undertaking with a cooking load being supplied successfully from such a scheme, nor do I agree with him that the maximum length of the low-tension cable should be 200 yards. I do consider, however, that any modern distribution system should have a high-tension ring-main. I have laid down seven schemes during the last few years and each one has such a system, because the main trouble is the voltage-drop which is experienced on the distribution system. I would advise the erection of kiosk substations in the areas as the load develops. I do not agree with the authors' suggestion that smaller schemes cannot be economically managed, as this statement is disproved by the three schemes to which I have referred. I do, however, agree with them that 11 kV should be standardized for feeders. With reference to voltage regulation (page 212), I have not found it necessary, except in one particular case, to provide voltage regulators. Every transformer should, however, be fitted with minus tappings giving a variation from 2½ to 10 per cent. I never install plus tappings, because in my experience bulk suppliers never deliver at a voltage exceeding the agreed value. I once came across a case where a consumer required a supply for a 50-h.p. motor, for which a low-tension main was laid. Six months later the demand increased to 100 h.p. I installed an automatic voltage regulator costing £200, which gave every satisfaction. The figures given in Table 25 for the cost per mile of 11-kV lines are similar to those I am actually paying for the work under my care. Horn-type air-break switches are, in my opinion, obsolete, and while they are inexpensive in first cost, I have found that they are very difficult to erect on account of troubles of alignment. I have standardized an ironclad oil switch-fuse which can be purchased for £24 and has a rupturing capacity of 50 000 kW. With regard to standardization, I think that consulting engineers and supply engineers generally would be well advised to accept a standard design of apparatus. I am amused at the criticism of the bulk-supply charges of the Central Electricity Board, as I have actually had a quotation almost identical with the figures quoted in the paper.

Mr. G. E. Barrett: On page 227 the authors set out the expenditure on rent, rates, and taxes, during the first 6 years, and also the gross revenue to be expected during the same period. Expressing the former as a percentage of the latter, it will be seen that the figure increases from 1·6 per cent in the first year to 4·6 per cent in the sixth year. Surely these average figures for rent, rates, and taxes, are not applicable to undertakings already operating in rural areas. I find from published statistics that the figure is in the neighbourhood of 7 to 10 per cent. The authors appear to be under the impression that the rates which are payable by the undertakings to the local authorities bear a relation to the capital charges. In actual practice the rates are a function of the gross receipts; the greater the receipts, the greater the amount payable to the local authorities. It is true, however, that certain deductions are made for working expenses. I am advised by valuers that revised assessments will be, as an average approximation, in the neighbourhood of 15 per cent of the gross receipts. If the average rate is assumed to be 13s. 4d. in the £ per annum, the amount payable by the undertakers to the local authorities will be 10 per cent of the gross receipts. This means that for every £100 collected by way of revenue, £10 is passed to the local authorities as a first charge on the undertaking, whether or not capital charges have been paid or are payable. This is a very serious item, and I know of a number of undertakings where assessments of this order of magnitude have already been made. Applying these figures to the working expenses shown for the Model Scheme, instead of a surplus being secured in the second year of operation, there will be a deficit in the first few years, and even at the end of the sixth year it is doubtful whether the undertaking will be able to show a profit. What the supply industry wants is a better opportunity for carrying out the work of rural electrification, and a fair reward for the enterprise shown. Relief from further legislation is desirable, but if we must have legislation let it afford better facilities for obtaining powers and wayleaves, and the removal of that anomaly whereby private generating plant is derated. Given such aid, there will always be both municipal and private undertakings sufficiently enterprising to promote on a commercial basis the development of electricity supply in rural areas.

Mr. W. E. M. Ayres: The authors appear to me to have produced a typically English paper, the whole attitude of which is conservative rather than progressive. The two outstanding features in any study of the economic aspect of rural electrification are load factor and cost of distribution per consumer. Load factor is mentioned on pages 201 and 202, and Fig. 6 purports to show the effect of load factor on the cost of supply. This curve, however, is plotted direct from the bulk-supply tariff of £3·25 per kW plus 0·2d. per unit. The real interest lies, of course, in the cost to consumers, and if losses, interest on distribution costs, management expenses, and maintenance, are taken into account the curve is of the form shown in Fig. K, which tells a very different story. From the two curves produced, the influence of distribution cost can readily be seen, and the effect of load factor on the cost per unit is emphasized even more than in the authors' diagram. Fig. 7 anticipates a maximum load factor of 25 per cent after 10 years, and Table 10 shows an anticipated saturation revenue for an 80-acre farm of £25 per annum.

There are, however, already rural districts in this country (which is backward so far as the development of rural electrification is concerned) with a considerably higher load factor, whilst the figures for South Sweden and parts of Holland exceed 60 per cent. Again, the assessment of £25 per annum is very low when one considers the utility of electricity on a farm. It is only based on the farmers' ability to pay "under existing conditions," whereas the enhanced speed and release of labour from low-grade work make a much larger power bill an economy. Horticultural frames, poultry houses, dairy machinery, and dairy hot-water supply, are invaluable loads for filling in the valleys and improving the load factor. Thermal storage should be strongly encouraged on the farm. It is only by means of a high load factor that the price per unit can be brought down to a figure which the farmer is able to pay. On page 212 the whole question of voltage regulation is dismissed in a short paragraph, although voltage-drop is one of the most serious troubles in rural service. One speaker has stated that a 10 per cent variation from normal voltage should be allowed for rural work, but such an allowance would be very retrograde. It is generally agreed that the present regulations are as wide as can be tolerated for electric cooking and such loads as use the power direct, i.e. without conversion into mechanical power. We have seen from Fig. K the large influence of capital expenditure per consumer, and it has been repeatedly shown that the cost of induction regulators is not an additional charge on the system but most frequently leads to an actual reduction of capital expenditure on distribution, whilst at the same time increasing revenue. The authors advocate overhead lines, but this also makes voltage regulation more necessary, as the reactive drop tends to predominate and additional copper section is of no avail. Low-reactance transformers are advocated because of the line drop to which the regulation is added, but why increase the cost of the transformer in order to save putting in a regulator when the latter gives so much better service? Protective reactances are being used in increasing numbers to enable one to utilize lower rupturing-capacity (and hence much cheaper) oil switches, and this again affects the voltage regulation. Bulk supply is allowed a 12 per cent variation from normal voltage, and this cannot be passed on to the consumer. It is seen, therefore, that numerous considerations point to the use of induction regulators for the maintenance of a satisfactory rural service, and the obvious course is to design the transmission and distribution system for the most economical conditions, induction regulators being included where desirable as a fundamental part of the scheme. Fully automatic voltage-control by this means is well tried and of proved reliability. I will give just one instance, typical of many, of its use in solving rural problems. A small village containing one or two large residences, a number of cottages, and the local inn, is situated 1 300 yards from the nearest point of supply. The villagers jointly agree to an annual electricity bill of £150 if the supply is given, and a 0·10-sq. in. overhead line is therefore run for a 400/230-volt 3-phase 4-wire supply. The voltage variations are found to be so bad that the engagement is repudiated. The installation of a small automatic induction regulator at the commencement of the line and a static balancer at the village, however, completely saves the situation.

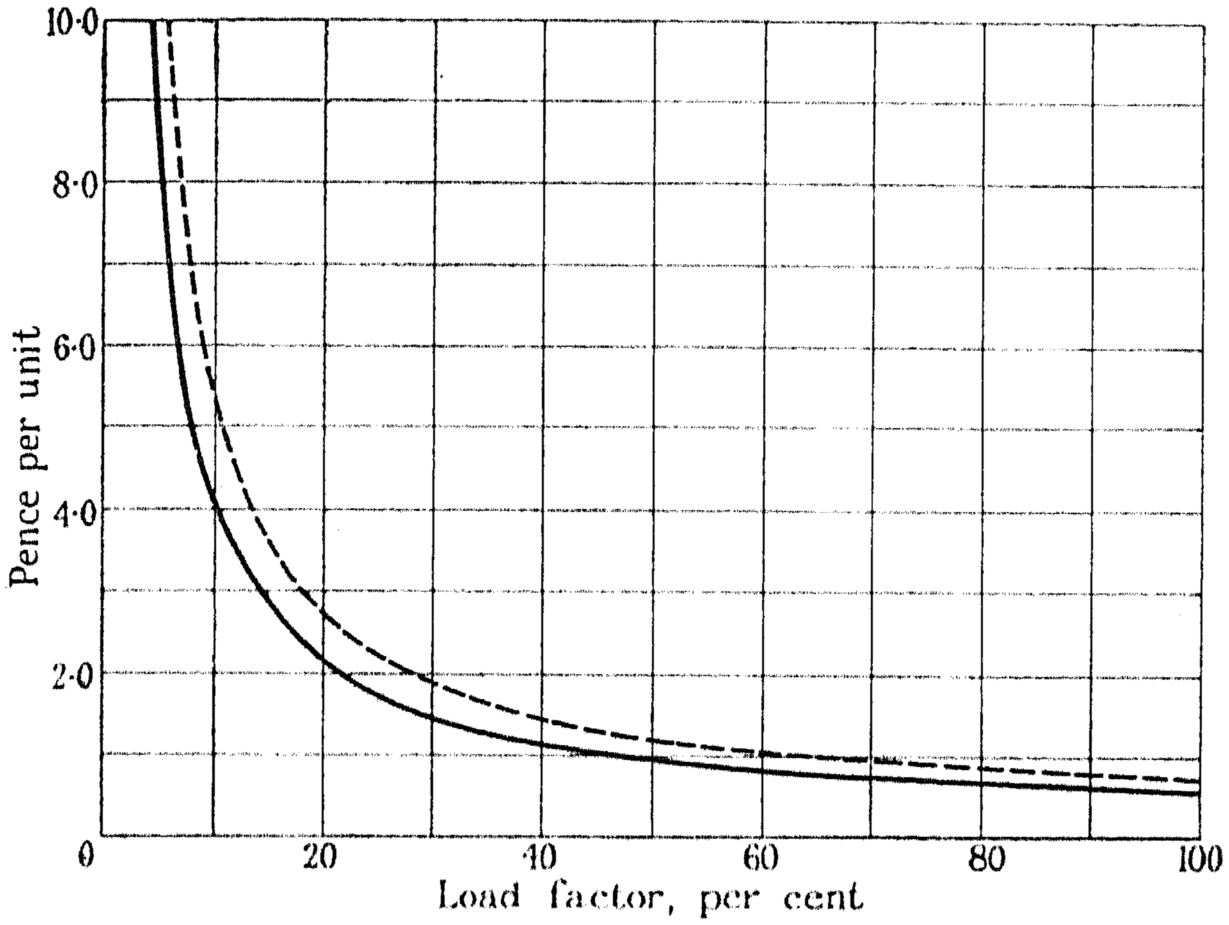

Fig. K.—Costs based on a mean of 0·35 kW maximum demand per consumer.

– – – – Capital expenditure £40 per service.
—— Capital expenditure £28 per service.

(The authors' reply to this discussion will be published later.)

MICROPHONIC FEED-BACK PHENOMENA IN RADIO RECEIVERS*

H. A. BROOKE, B.Sc.(Eng.), Graduate.

(*Paper received* 19*th October*, 1931.)

Little has so far appeared in print on the subject of microphonic feed-back phenomena in radio receivers, particularly as regards those originating in the radio-frequency portion of the apparatus. It has been known for a long time that such a feed-back occurs between the first valve of a multi-stage audio amplifier and the loud-speaker which it operates, if sound waves from the latter impinge on the first valve or if the loud-speaker vibrations are mechanically transmitted to the first valve.

With the advent of self-contained receivers, e.g. radio gramophones, midget, console, and portable receivers, several difficulties have arisen in connection with microphonic feed-back.

The first difficulty experienced is a plain audio-frequency feed-back between the detector and the loud-speaker. This can be effectively overcome only by suitable design of the detector-valve electrodes.

The second difficulty is due to what may be called amplitude modulation, in the receiver itself, of a radio-frequency signal. This usually occurs in the first stage of the radio-frequency portion of a self-contained receiver. If the electrodes of the first valve, in particular, are not mounted on supports which will damp their natural vibrations, there will be periodic variations in the amplification factor of the valve at the natural frequency of either the grid or the cathode system, or of both together, thus producing at these frequencies amplitude modulation of any received signal. The result is a sustained note emitted from the loud-speaker, if the low-frequency gain of the receiver be sufficiently high to overcome existing damping.

The energy feed-back will, of course, build up until limited by the maximum power output of the receiver. The remedy lies in a suitable design of the valve electrode-supports, as the valves and the loud-speaker must of necessity be mounted in the same cabinet. Since this feed-back is both mechanical and acoustic, it is of very little assistance to employ sprung valve-holders alone; these only eliminate the transmission of mechanical vibrations to the valves.

The third problem arises in the superheterodyne receiver, and is due to frequency modulation of the oscillator. This effect is very pronounced in this type of receiver if properly designed electrically for high adjacent-channel selectivity; for, since the narrow frequency-band of the intermediate-frequency amplifier is between the oscillator and the audio detector, a frequency displacement of the oscillator of 10 kilocycles will cause the signals measured on the audio detector to disappear completely.

The frequency modulation of the oscillator is the result of changes in the tuning capacity, owing to mechanical vibrations of the variable condenser. These vibrations are of two kinds:—

(*a*) " Reed " or " diaphragm " vibrations of the rotor and/or stator end-vanes.
(*b*) Transverse vibration of the rotor gang-structure.

In case (*a*) mentioned above, " reed " or " diaphragm " vibrations of the vanes are usually produced by acoustic feed-back from the loud-speaker, and sufficient damping is usually obtained by bracing the vanes where possible.

The second kind of vibration is usually the more troublesome, as it generally causes a greater change in capacity for a given amount of displacement of the parts concerned. If the rotor structure consists of a number of gangs so that the length of the spindle is more than about 10 times its diameter, it should be supported in more than two bearings, or else definite means should be provided at points along its length for damping out transverse vibrations.

If, for any reason, it is impossible to make the condenser rotor-assembly not subject to resonant vibrations, the amount of feed-back, which in this case is mechanical between the loud-speaker and the condenser, must be reduced. This may be achieved by mounting the radio receiver chassis on soft rubber blocks, thus introducing resistance to mechanical transmission between the loud-speaker and the condenser.

It should be realized that all these effects are independent of radio-frequency and intermediate-frequency gain, and depend entirely on the low-frequency gain, the amount of feed-back present, and the degree of selectivity.

It may be worthy of note that the low-frequency gain of a radio set varies with the radio-frequency or intermediate-frequency input to the detector, in accordance with the law of rectification, and therefore the feed-back effect depends also on the condition that the radio-frequency or intermediate-frequency input to the detector shall be sufficient to cause the low-frequency gain to be such that the effect can build up.

In the case of the first and second problems, the only possible solution lies in a suitable design of valve electrode-supports, since it is very difficult to reduce the amount of acoustic feed-back in so confined a space.

These problems present many interesting difficulties, which, as has been stated, may be overcome by careful attention to the above-mentioned points in design.

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* The Papers Committee invite written communications, for consideration with a view to publication, on papers published in the *Journal* without being read at a meeting. Communications (except those from abroad) should reach the Secretary of the Institution not later than one month after publication of the paper to which they relate.

REFLECTION METHODS OF MEASURING THE DEPTH OF THE SEA.

By Commander J. A. SLEE, C.B.E., R.N., Member.

(*Paper received* 13*th October*, 1931; *read before the* WIRELESS SECTION 2*nd December*, 1931.)

SUMMARY.

This paper deals only with the practical application of the idea of sounding by reflection as applied to the needs of navigation in the mercantile marine. It does not profess to deal with any original researches on the subject, but is only a statement of the present state of the art, especially with reference to the mercantile marine of this country.

In order to keep the paper within reasonable limits all detailed description of apparatus has been omitted. Theoretical discussions on the subject, together with detailed descriptions of apparatus, have appeared from time to time in the technical Press. The *Hydrographic Review* (1930, vol. 7, No. 2) contains references to previous articles on this subject. Most interesting papers can also be found in the *Bulletin de l'Association Technique Nautique et Aéronautique* (No. 34 of 1930) and in *Elektrische Nachrichten-Technik* (1929, vol. 6, p. 165). The principal formulæ referred to have been collected in an Appendix and have all been extracted from papers by Prof. Langevin.

(1) INTRODUCTION.

The fundamental principle is to make a disturbance in water and to time the return of the echo from the bottom of the sea. The object of this paper is to put on record the present state of perfection with which this work can be carried out in practice, and to describe the chief methods now in use. It has been proposed to measure depth by the "angle of reflection" method and by the "standing wave" method, but as far as is known these methods are not now in use at sea.

The fundamental idea of reflection sounding is not new. It is vaguely outlined in documents dated 1887, and in a document dated 1897 there is a more precise statement. The author has not been able to find any record of anything having been achieved on a sea-going scale until the War period. At the end of the War a considerable amount of knowledge which had been gained in the study of this problem for warlike purposes was made available, and since then steady progress has been made, the rate of advance increasing yearly as advantage has been taken of experience and as the demand for satisfactory apparatus has increased. Many deep-water surveys have been made with rather special arrangements, 4 000 fathoms having been measured. The ordinary commercial requirements are twofold. Ordinary big-ship navigators are very interested in depths from a little over 100 fathoms downwards, and are particularly anxious to read from 2 to 10 or 20 fathoms of water under keel; trawlers demand much greater depths, at least as great as 350 fathoms, and it seems probable that this requirement will increase in the future.

The vast majority of fish are bottom feeders—the surface and mid-water feeders are rare. The staple food is weed of various kinds, or the small creatures that exist at or very near the bottom. The best depth for certain types of fish varies with the locality and the time of the year, the depth being fairly precise for a given locality. The fish are usually found on the slope of the sea-bed, the trawl being dragged along a contour line. If the trawl is taken too far up the slope, or too far down it, the quality and usually the quantity of the catch deteriorate.

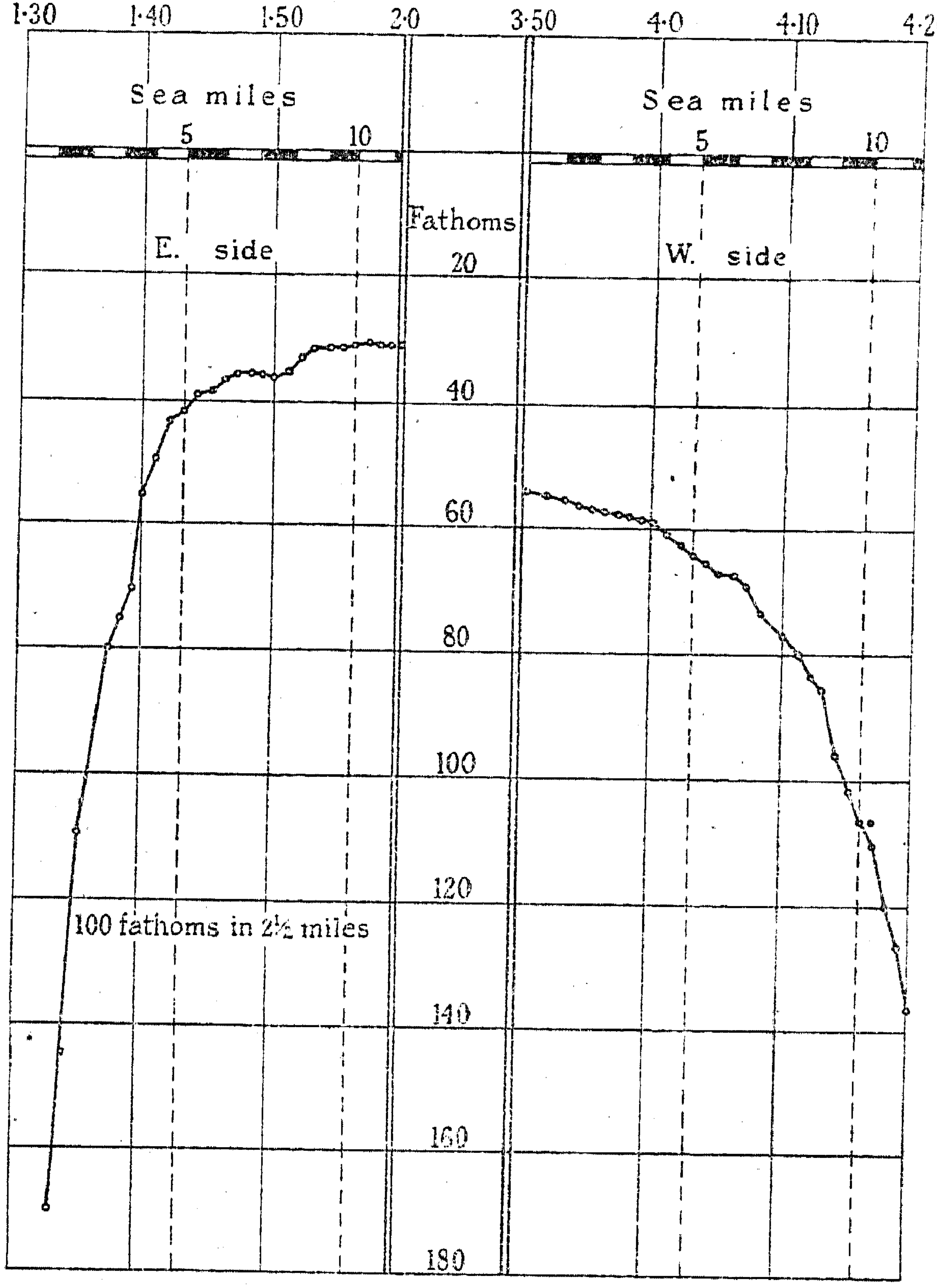


FIG. 1.—Graph of depth soundings taken at 1-minute intervals over southern end of the Great Banks.

On both sides of the Atlantic the bottom rises very abruptly from great depths to about 400 fathoms, after which the slope eases a little to about 100 fathoms. At less depths the sea floor is more nearly flat. On the European side the belt from 100 to 400 fathoms is fairly wide, and this is the main trawling area.

As a specimen a graph made up from soundings taken at 1-minute intervals may be of interest (see Fig. 1). It represents the part of the westward-bound liner track to New York which passes over the southern end of the Great Banks.

The rate of propagation of elastic waves in sea water has been established, and may be taken at its average value of 4 900 ft. per sec. Translated into the language of navigation this means a depth of 408 fathoms for each second that elapses between the time of emission and the time of reception of the echo. Since ordinary navigators reckon the depth of water by the fathom, the unit of time which has to be dealt with is 1/408 of a second, and a large proportion of the problems of the subject consists in the difficulty of making these measurements of very short intervals of time with sufficient accuracy and by means which are suited to the everyday conditions under which they must be used.

(2) Analysis of the Practical Problem.

The whole problem divides itself into four distinct parts:—

(a) To set up the necessary elastic wave in the water.
(b) To detect the return of the echo.
(c) To disentangle the echo from unwanted signals of all kinds.
(d) To make the measurement of time and to indicate the resultant depth of water.

With regard to (a), the elastic wave can be of such a regular and sustained nature that the effects of resonance can be made use of, or it may be so highly damped as to approach to the nature of a single impact. In the case of resonant waves there is a wide choice of practicable frequency. Apparatus now being manufactured comes under one of two headings, (1) "single impact," (2) resonant at a frequency too high for human hearing, the audible-frequency resonant wave being at present out of fashion. In any case, the period during which transmission lasts must be very short indeed in order that at least the greater part of the energy of transmission shall have died away before the echo returns. In shoal water there is no doubt that this echo is received through the last part of the transmission wave when using the more highly resonant types of transmission.

A form of multiple hammer has also been used, the blows following one another at a time-interval corresponding to the frequency desired. This class of emitter allows greater power to be employed, and has been worked up to a frequency of about 20 000.

The effects of magneto-striction have also been used to form a resonant emitter.

A combination of single-impact and audible resonance has also been used, the hammer blow being struck on the end of an elastic steel rod, the longitudinal vibration of which provides the frequency of the elastic wave emitted.

With regard to (b), the present types of receiver are either hydrophones—that is to say, special types of microphones—or employ the piezo-electric principle. The effects of magneto-striction have also been employed for subaqueous receivers of various sorts.

With regard to (c), there are two principal methods, (1) the rough but effective plan of using so much transmitted power that the returning echo shall be considerably above the noise-level, or (2) the more delicate method of taking advantage of the effects of resonance and of directional reception to select the required signal.

With regard to (d), the most successful methods now in use may best be described as oscillographic. If practically constant relative motion of some kind of index over a scale can be assured, and if transmission takes place as this index passes the zero, its disturbance by the returning echo will mark a point on the scale which indicates the depth in fathoms. The index is usually the stylus of an electrolytic or mechanical recorder, or a spot of light which may be deflected by the returning echo, or a spot of light whose brilliance may be varied. With such devices the occurrence of any unwanted signal before the echo returns does not prevent the correct reception of the echo when it does arrive.

The following very brief outline of the action of the leading types of oscillograph may make the subject clearer.

Class (1).—*Those which leave a permanent or semi-permanent record.*

The paper is kept moving slowly at a known speed, and a stylus is run over it at right angles to the direction of motion of the paper at a speed selected with reference to the depth to which the instrument is designed to work. The contacts which determine the moment of transmission are also actuated by the same mechanism.

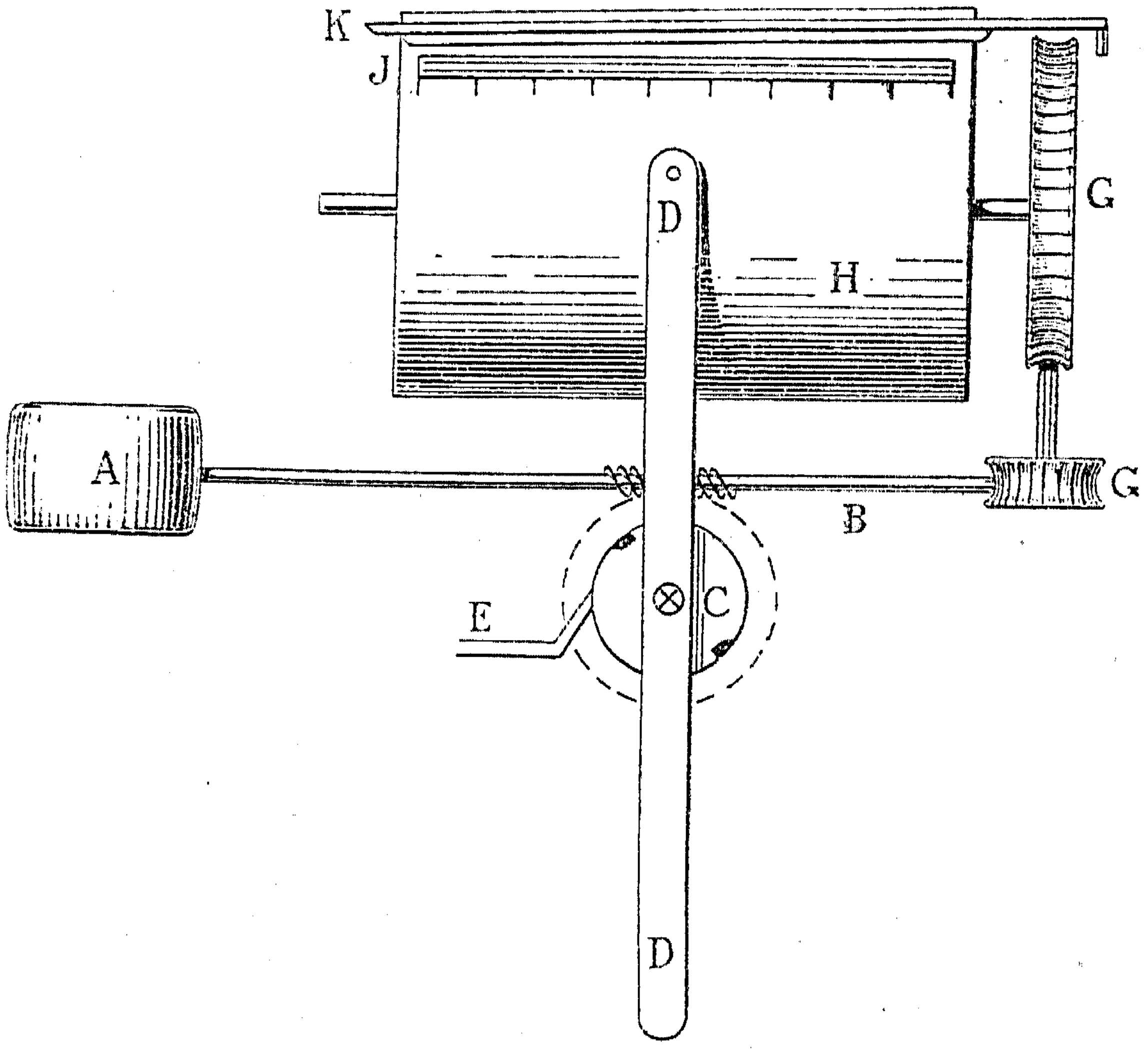


Fig. 2.—Mechanical arrangement of typical recording oscillograph.

A = motor.
B = first spindle.
C = emitting contact drum.
D = stylus arm, double-ended.
E = emitting contacts.
G = paper drum.
J = scale-marking comb.
K = time line bar.

Whatever the action of the stylus may be, it occurs at the moment of emission, and as all three things—paper movement, stylus movement and emission—are controlled by the same mechanism the series of actions will trace a line along the paper near its edge. The position of this emission line is usually adjustable with reference to the depth scale so that it coincides with the depth of the emitter. The return disturbance will cause the action of the stylus to take place again, thus making a mark at the depth of water under the ship. A repetition of this sequence of events will draw a contour of the bottom of the sea.

There are two practical difficulties. The first is to synchronize the formation of the emission mark with the real commencement of the emission. This is sometimes done by allowing the receiver to make the emission mark, sometimes mechanically, but if shallow water is being dealt with on an open-scale instrument there is plenty of room for error, and this point requires careful attention. The second practical difficulty lies in the fact that the stylus generally has to move fast—say 2 ft. per second—and in consequence it is difficult to control ink. Therefore the action of the stylus is often electrolytic, that is to say the paper is damped with some suitable electrolyte, the stylus forming one pole and a metal backing behind the paper being used as the other. Alternatively, the stylus may scratch a white line by removing the surface of paper covered with lamp black, or may scrape the surface from waxed paper. In some instruments the depth scale is marked on the paper by the action of the stylus, which is artificially operated for the purpose, or by a permanent comb independent of the stylus (see Fig. 2).

With apparatus of this nature the occurrence of an unwanted signal is indicated by an extra mark on the paper. This in no way hinders the correct spot from being marked, and so long as these unwanted marks are not too numerous they do no real harm.

Class (2).—*Those which do not leave a record.*

All the instruments of this nature are optical, and perhaps should be called oscilloscopes. There are two main types. In one the light is made to appear at the end of a revolving arm moving round a fixed circular scale, showing a very quick flash as the arm passes the emitting point, and another on the return of the disturbance.

Alternatively a light spot may be made to traverse along a straight scale. The light spot " kicks " at emission, and again on the return. By careful attention to the design of the amplifier and to the damping of the mirror movement the return indication can be made to take a definite form, and this form will vary considerably according to the formation of the sea bottom. A smooth hard bottom will cause a sharp and clear-cut tooth to appear, a soft slimy bottom will make the base of the tooth much longer, and rocks and large boulders will give the top of the tooth a serrated edge instead of a single peak. This does not imply any uncertainty in reading the scale, as the reading is taken from the left-hand side of the tooth.

The optical system is briefly as follows (see Fig. 3). A beam of light which is nearly parallel is trained on the mirror of a very robust and specialized reflecting galvanometer carrying a concave mirror. The beam passes to a plane mirror which swings on a vertical axis, and the beam comes to a focus on a cylindrical scale. Emission and return make the light spot kick vertically by agitating the reflecting galvanometer, and the swinging mirror makes it traverse the scale at a predetermined speed. In this instrument the mirror has a quick-return motion, and the transmitting contact is worked by a tappet action carried by the mirror spindle. Emission takes place when this contact opens. The light spot is disturbed by induction when this contact closes, but this takes place during the rapid recovery of the light spot, when its movement is too quick to be visible. Most of the disturbance of the light spot takes place when it is off the scale and shielded from view.

Other methods of timing and indicating have been used, in particular aural and semi-permanent indication.

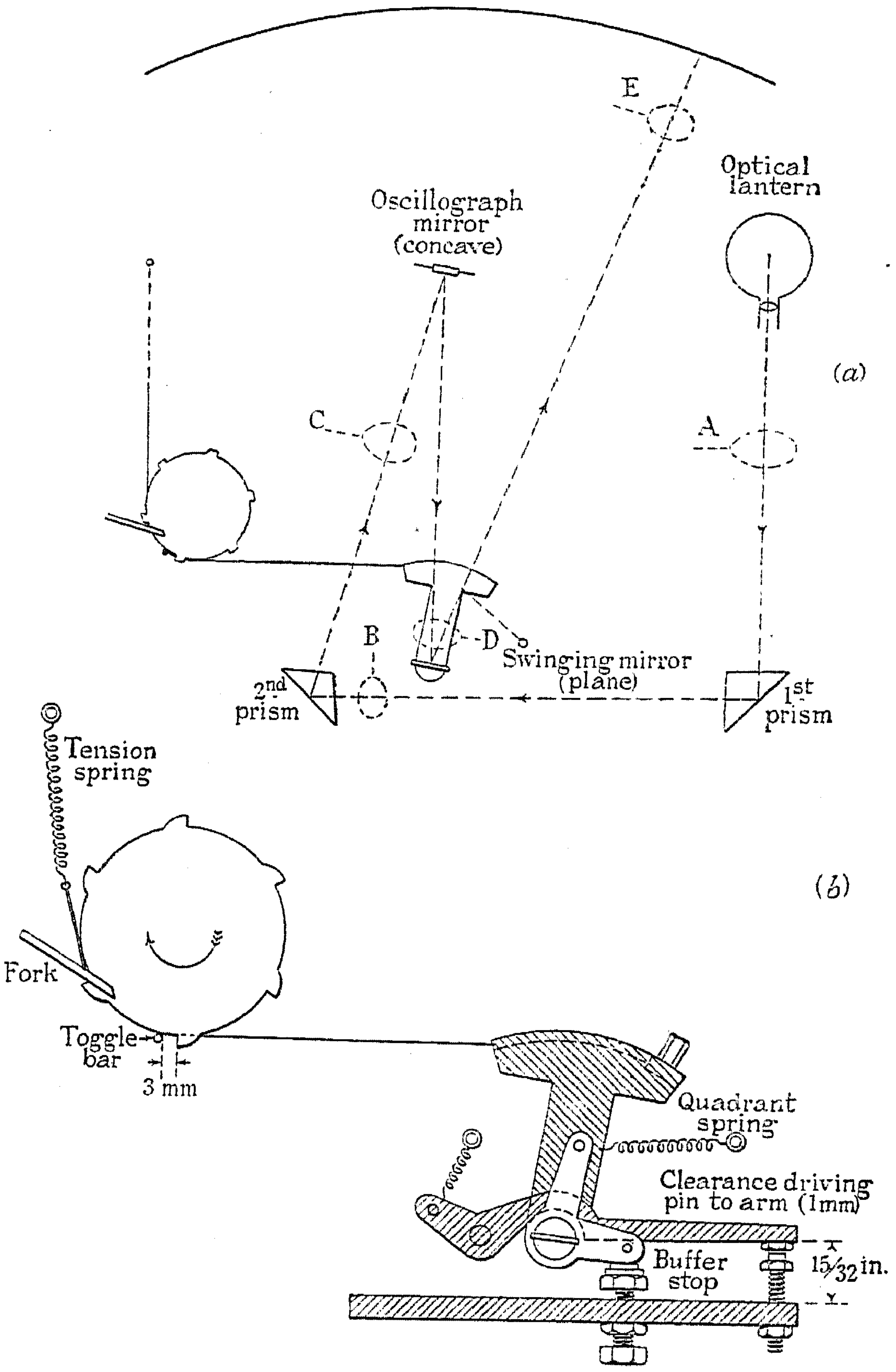


FIG. 3.

(*a*) Optical system.
At A, B, and C, a screen shows an image of the filament.
At B a screen shows a rectangle of light.
At E there is a sharp spot.
(*b*) Quick-return system for mirror.

The most important of the former consists in listening for a very short period at a time for the combined sounds of noises and returning echo, the receiving telephones being short-circuited except for this very short period. The time after emission at which this period of hearing takes place can be varied by moving a contact round a rotating disc. The quality of the sound heard in the telephones when noises only are present differs materially from the sound heard when noises plus echo are present, so that the position of the moving contact referred to above—which may carry a depth scale—will allow the depth to be read off when the sound indicative of noise plus echo is heard.

The semi-permanent indication method consists of allowing a pointer to start on its travels at the moment of transmission and to stop it and hold it locked for any desired period on the return of the echo. Such a method has many attractions, but for practical reliability it demands an extremely high degree of freedom from unwanted noises because its pointer, once it is stopped, will remain stopped, and any noise occurring before the return of the echo will cause an entirely wrong depth to be recorded. The accuracy with which such instruments can be made to measure short intervals of time is remarkable, a precision of about 1 milli-second being attainable.

In order that any of these may operate, the first essential is some kind of source of movement to drive the timing mechanism at a known and constant speed. Several methods of control have been employed, such as a motor held to a constant speed by a centrifugal governor, sometimes used to slow the armature directly by added friction on a brake drum. Sometimes the governor is used to work a field regulator, giving indirect control.

Phonic motors, which are in effect small single-phase synchronous motors the supply to which is interrupted direct current caused by the closing and opening of contacts driven by a self-maintaining vibrator or tuning fork, have also been used, as have motors with simple hand control and a more or less complicated form of indicator showing whether the speed is correct, too high, or too low. Simple clockwork, with a governor similar to that of a gramophone, is also used to a great extent. Any of these will keep its speed constant to well within 1 per cent, which is all that is required for navigation.

(3) PRINCIPLES OF TYPES OF EMITTERS NOW IN USE.

The single-impact emitters now in use are electric or spring-driven hammers of some kind, or in some cases pneumatic hammers. Explosive charges have also been used. For instance, a steel tube is fixed with its open end in the water, the top being fitted with a breech block. A blank rifle cartridge is inserted in this tube and fired when the emission is required. Again, a rifle can be fired over the side, the impact of the bullet on the surface of the water being used to start the elastic waves.

The counsel of perfection for commercial purposes is to avoid the necessity of dry-docking the ship so as to pierce the skin in order to install a "hammer" with its face in contact with the water. There is an existing system in which the blows are struck directly on the frame of the ship, but it appears that this practice is liable to cause leaks in course of time. In some cases a small watertight tank is fitted, the skin of the ship being one of its walls. This tank is filled with water kept under a pressure approximately equal to the hydrostatic pressure, and the blows are struck on this tank or by means of a hammer-face in contact with the water in the tank. In the majority of installations now on the market the transmitter has to be fitted when the ship is out of the water.

The most remarkable emitter is the high-frequency piezo-electric instrument. As commercially developed its frequency is approximately 37·5 kilocycles per second, representing an elastic wave (in salt water) about 4 cm long. A comparatively small disc oscillating axially at this frequency will give highly directional transmission, the commercial article of 8-in. diameter confining the majority of the energy radiated within a cone having an angle from wall to axis of about 6° (see Fig. 4).

The construction of the active part of this "projector" is most ingenious. It consists of a thin layer of piezo-electrically active pieces of quartz fitted together in a perfect mosaic, all the parts being fastened together and to the surfaces of two steel discs, between which it is placed, with a special form of cement. Provided that the adhesion due to the cement is perfect between the parts of quartz and between them and the steel, the whole mass acts piezo-electrically as one, and at a frequency which is very different from that of the quartz alone. The whole is so constructed that its thickness is $\frac{1}{2}$ wavelength at its resonant frequency, and the axial movement of the outer faces when electrically excited at a given voltage at its own frequency is about 17 times that of the quartz pieces alone. This piezo-electric element, a sheet of quartz pieces mounted between two steel discs, is also a condenser. It is usually mounted with its outer face in contact with the sea, its inner face being highly insulated. Recently the piezo-electric element has been mounted internally, its lower face resting on a steel plug $\frac{1}{2}$ wavelength long. The outer face of this plug is in contact with the sea.

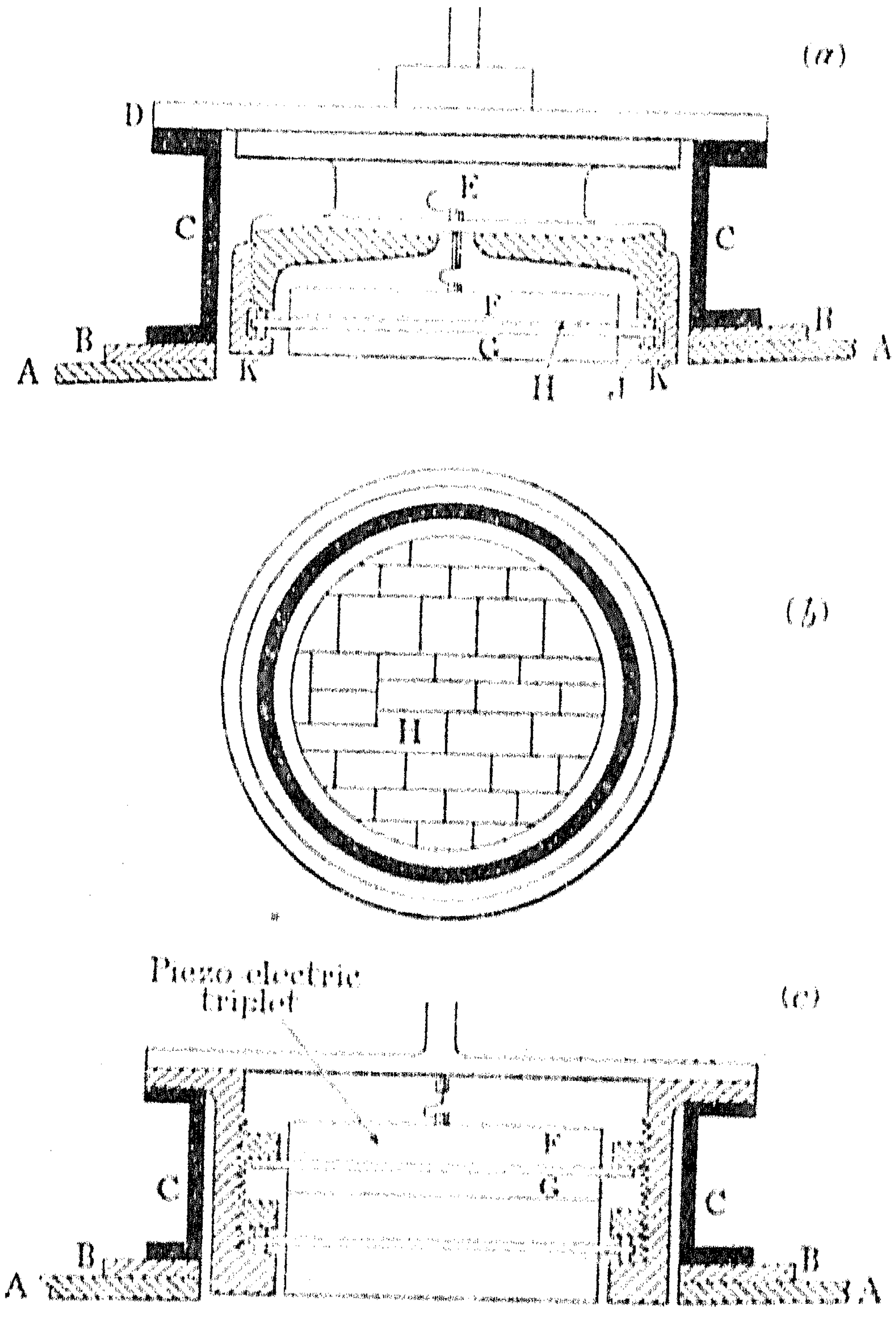


FIG. 4.

(a) Section through a projector as fitted.
A = skin of ship.
B = stiffening ring.
C = hull casting.
D = projector mounting.
E = projector case.
F = inner plate.
G = outer plate.
H = quartz.
J = rubber pads.
K = cap.
(b) Section through quartz.
(c) Demountable projector.

When this mounting is used the active element can be changed when the ship is afloat, but the mounting has to be fixed in the ship when she is out of the water.

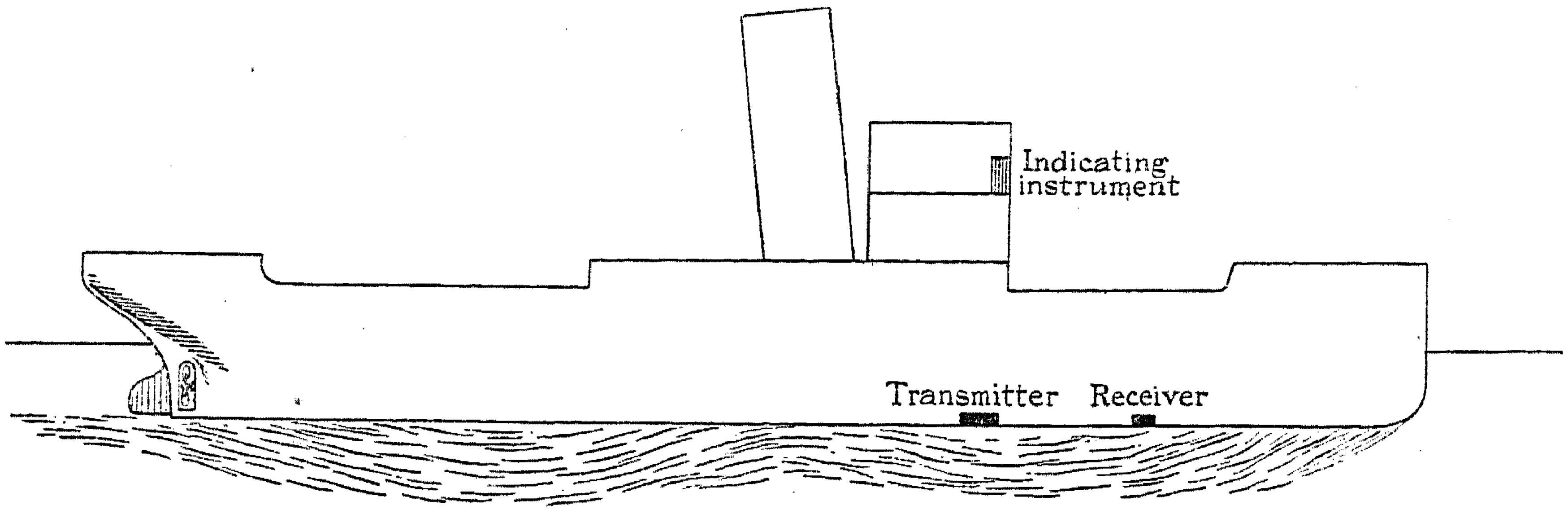


FIG. 5.—General lay-out, showing turbulence streams.

Such an article is obviously also a directional piezo-electric receiver, and in practice the same apparatus performs the duties both of transmission and of reception.

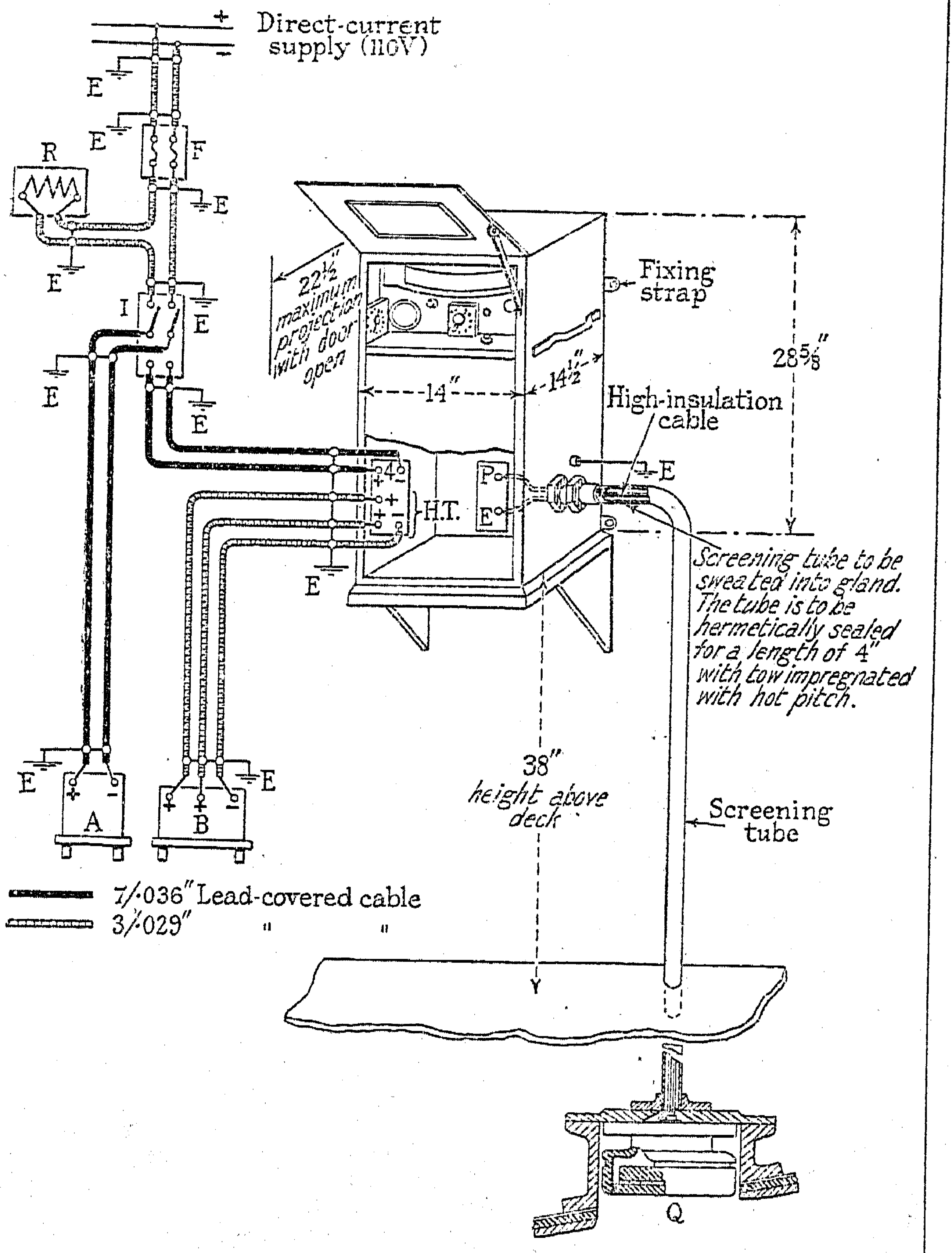

+ Direct-current supply (110V)
−
E
R
F
I
22½" maximum projection with door open
Fixing strap
28⅝"
14"
14½"
High-insulation cable
H.T.
P
E
Screening tube to be sweated into gland. The tube is to be hermetically sealed for a length of 4" with tow impregnated with hot pitch.
38" height above deck
Screening tube
A
B
7/036" Lead-covered cable
3/029" " "
Q

FIG. 6.—Lay-out of piezo-electric installation.

A = 4-volt battery.
B = H.T. battery.
E = earth connections.
F = ironclad cut-outs.
I = double-pole change-over switch.
Q = projector.
R = charging resistance.

(4) GENERAL LAY-OUT OF INSTALLATIONS.

When using the "single-impact" systems the installation consists of three main parts—emitter, receiver, indicator. The emitter and receiver are usually some distance apart, and when reading shallow soundings this must be allowed for, since the path traversed by the elastic wave may then be substantially more than twice the distance from the bottom of the ship to the bottom of the sea. This correction is usually made automatically. The indicating portion, which may be regarded as including the mechanism which controls the emission and any amplifying or similar devices which may be required, is usually on the navigating bridge. When installed in this way there is no direct connection between the emitter and receiver, and the receiver is to a great extent sheltered from the direct effect of transmission (see Fig. 5).

It should be noted that the measurement which is actually taken is the depth of water between the bottom of the ship and the bottom of the sea. As charts are marked with the depth below the surface a correction must be made for the depth below the surface of the emitter and receiver. This correction is purely additive and is usually applied automatically.

In the supersonic installations the emitter and receiver are one and the same. The receiving amplifier is therefore subjected to the full transmission voltage at its input terminals. The piezo-electric projector is excited by means of what may best be described as a very small spark transmitter of the quenched-spark type, making use of only one spark for each emission [see Fig. 8 (*b*)].

(5) WATER NOISES, ETC.

In the practical application of these methods of sounding by far the greatest difficulty is that of overcoming water noises. The rush of water past the ship's skin sets up noises in any kind of receiver, and in addition there is the question of turbulence eddies. The water is thrown out by the ship's bows and returns again at some point along her hull. The water noises over the areas where these turbulence eddies return are redoubled. Not very much is known about this subject. It is certain that the position of these turbulence areas alters with the speed of the ship, and with her draught and trim. The boundaries of these patches seem to be quite sharply defined. The most hopeful place seems to be somewhere about one-quarter of the ship's length from forward. Water noises are always worse in shoal water than in deep water, due to such causes as the reflection of the bow wave from the bottom of the sea.

In addition to the water noises due to forward speed, noises are also caused by rolling. When a ship is rolling, the wash of her bilge keels, if it reaches the receiver, will cause most severe water noises, and so will the eddies due to a condenser outlet, an ash ejector, or anything similar that causes water to flow in or out (see Fig. 5).

(6) Absorption Effects.

In addition to water noises there is another well-marked effect. The disturbance of the water causes the formation of a large number of air bubbles, often most minute, and these greatly increase the rate at which energy is absorbed by the water from the elastic wave passing through it. The trouble due to bubbles is worse near the surface than at greater depths. It is not as a rule very serious at depths exceeding 20 ft. Air bubbles will collect in any recess in the ship's bottom, quite a large amount of air being found in any pocket of this nature after a few days at sea, especially in bad weather. There is a zone of disturbed water surrounding a ship in which the absorption is vastly higher than in "solid" water. This zone is as a rule about 3 ft. thick and its effect is to cause a definite reduction in anticipated range.

The rate of propagation of an elastic wave varies according to the salinity and temperature of the water, the accepted extremes being 4 750 ft. per sec. for the Baltic, which is nearly fresh, and 5 100 ft. per sec. for the Red Sea, which is saturated. The average for the Atlantic Ocean is 4 900 ft. per sec., and this is the wave velocity usually adopted.

The velocity of propagation does not alter very much, but the absorption coefficient varies greatly. If the water to be penetrated by the elastic wave is composed of layers of differing salinity or temperature a certain amount of reflection takes place at the limiting surfaces, and considerable variations in the effective attenuation may result. The coefficient of reflection of different natures of sea bed also varies very much, and it may be stated that in normal conditions the proportion of received to transmitted energy at any given depth may vary rapidly and continuously over a range of about 10 to 1.

There is a classic formula (see Appendix) which gives the rate of absorption for an elastic wave passing through homogeneous water. This rate of absorption is small, and from it it is easy to obtain a good idea of the range which can be covered directly under known conditions. This formula, however, takes no account of disturbed or aerated water. The presence of bubbles in water adds enormously to the absorption.

(7) Degree of Accuracy Attainable.

The degree of accuracy that can be maintained in practice clearly depends on the following factors, which are mutually independent:—

(*a*) The constancy of velocity of propagation of the elastic wave through the water.

(*b*) The constancy to be expected of the time-measuring arrangements.

(*c*) The constancy to be expected in the time-lags of any electrical or mechanical systems which may be associated with (*b*).

(*d*) The ease and certainty with which the scale can be read.

The figures previously quoted for the velocity of propagation of elastic waves in sea water show that the overall limits are not very wide, and if the extreme cases are neglected the probable figure for, say, the Atlantic Ocean hardly varies by 1 per cent from the mean value. Even if this discrepancy is accepted, reflection sounding remains by far the most accurate method known. In fairly shallow water an error of 1 per cent is so small that its equivalent value cannot be measured, and at depths such as 100 fathoms where there is some prospect of measuring time in a sea-going fashion to a sufficient degree of accuracy to detect an error of 1 per cent there is no other means of checking within this degree of precision.

The velocity of propagation of an elastic wave in water rises with temperature, the values for sea water of average specific gravity 1·02 ranging from 4 830 ft. per sec. at freezing point to 5 045 ft. per sec. at 90° F., for depths ranging from zero to 100 fathoms. The velocity of propagation rises with the density. In fresh water the velocity is 120 ft. per sec. below the above figures, and in very salt water (sp. gravity 1·04) it is 65 ft. per sec. above them. The velocity rises with pressure, that is to say with depth, but this correction is not perceptible at depths less than 100 fathoms. As a general rule water at great depths is cold, and it is not likely that the average of 4 900 ft. per sec. is often exceeded to an extent which can interfere with navigation.

A plain and simple fine wire with a lead at the end is obviously the most accurate check, provided, of course, that the ship is absolutely stationary at the time that the measurement is taken. It must also be assumed that there are no currents below the surface. Even so, the problem of maintaining the marking of the wire itself within 1 per cent is very difficult, if not insoluble, under sea conditions. The scending of a ship in a slight ground swell will make the measurement to within 1 fathom very difficult. Also, the sea bed is not a flat, level plain, and the deep-sea lead may fall into a hole, or on to a boulder no bigger than an armchair, which would show an apparent inaccuracy of ½ fathom.

The accuracy which can be expected of the time-measuring arrangements, as such, can be determined fairly easily if the load on the driving mechanism remains constant, or nearly so, through the whole cycle of operation. If this is not the case the measurement is more difficult.

The electro-mechanical lag of the various parts can also be measured, and if arrangements are made so that the lag of one part compensates for the lag of another, then the resultant error is only the difference between these two, and is likely to be too small to be worth consideration in a navigational instrument. For instance, the ordinary small relay worked at comparatively high voltage through a non-inductive resistance of appropriate value will not operate in 1 milli-second, and will operate for certain in less than 2 milli-seconds. If two such articles compensate for one another the maximum possible difference is less than 1 milli-second —about 2 ft. in terms of a sounding device.

The ease and certainty with which the movement of an index over a scale can be read is, generally speaking, more of a human than a physical problem. It is more properly, a question of the effect produced on the eye or ear. The overall accuracy of a complete installation can be tested by direct observation by working it horizontally over a known range; for instance, by measuring the distance from one side to the other of a large dock. This is rather a cumbersome process, especially if checks are required at several ranges. A perfectly satisfactory substitute can be found in the case of any form of transmitter which has strongly directional properties, working in conjunction with the oscillograph type of receiver. Such a transmitter can be so mounted as to transmit horizontally along the length of quite a small tank, when the original reflection can be observed, in addition to a large number of subsequent reflections. Any indicating device of the oscillograph class will show each of these reflections, and if they all appear on the scale at a distance apart equal to the length of the tank it is certain that the indicating device is working correctly over whatever portion of the scale the subsequent reflections may cover. There is no difficulty in working with as many as 20 or 30 reflections.

(8) Miscellaneous Notes.

It has been mentioned earlier in this paper that the coefficient of reflection of the sea bottom varies greatly with its nature, and in addition to this it must be realized that the slope of the sea bed may have a great deal to do with the strength of the reflection on its return. A patch of steeply-sloping bottom may throw the greater part of the reflected energy clear of the ship, and so make the reflected signal very much weaker than would be expected. This is especially true of a smooth hard bottom; if the slope is very rough or covered with large boulders there is generally less reduction of signal strength, due to less complete reflection in the wrong direction. A loose shingle bottom with a strong current running over it so as to keep the pebbles moving seems to present about the lowest known coefficient of reflection. Small vessels in shallow water in very heavy weather have reported an abnormally high absorption of energy in the wave, due no doubt to the very high degree of aeration which would exist under such conditions.

In most systems of reflection sounding it is customary to repeat the operation of sounding several times per minute. The interval between transmissions must be long enough to make certain that indications will not be received the second time round the cycle of operations. For instance, supposing the scale of an instrument to be graduated to 100 fathoms, it would be possible to repeat the whole cycle of operations 3 times per second, but at a moment of low absorption in the water and high coefficient of reflection it is quite likely that indications would be obtained in, say, 150 fathoms of water, and these would show up at about the 30-fathom mark one complete cycle of operations out of place.

If a directional emitter is used it is desirable that the interval between soundings should be very much less than the rolling period of the ship. It is possible so to control the emitter that emission only takes place as the ship rolls through the upright position. This is rather a pretty problem, as the control cannot in practice be mounted near the rolling centre, and its behaviour is more a matter of inertia than of gravity.

If very powerful transmission is used in very shallow water, a second reflection is often observed, showing up at double the depth under keel. This is due to retransmission of the returned reflection from the bottom of the ship to the bottom of the sea and back a second time to the ship. A second class of false indication is sometimes obtained; this appears to be due to the reflection of the original transmission first on the bottom of the sea and then from the surface. In practice these subsidiary indications can as a rule be disregarded. If the power of the emission or the sensitiveness of the receiver or indicating device is reduced to something reasonable with regard to the depth of water, these subsidiaries will pass unnoticed, if they do not entirely disappear.

The general connections of the piezo-electric installations are in many ways analogous to those of a simple wireless installation, the piezo-electric element representing the active part of the aerial, and the capacitance of the leads connecting it to the source of excitation being parasitic and antagonistic to good transmission and reception. In consequence, there is a practical limit to the length of the connecting leads if the piezo-electric element is connected directly to the excitation circuit. This difficulty is entirely overcome by separating the excitation and piezo-electric element circuits, acting upon the latter by means of a power-line circuit consisting of two cores with a transformer coupling at each end. One of these transformers couples the excitation circuit to the line circuit, and the other transformer couples the line circuit to the circuit of the piezo-electric element.

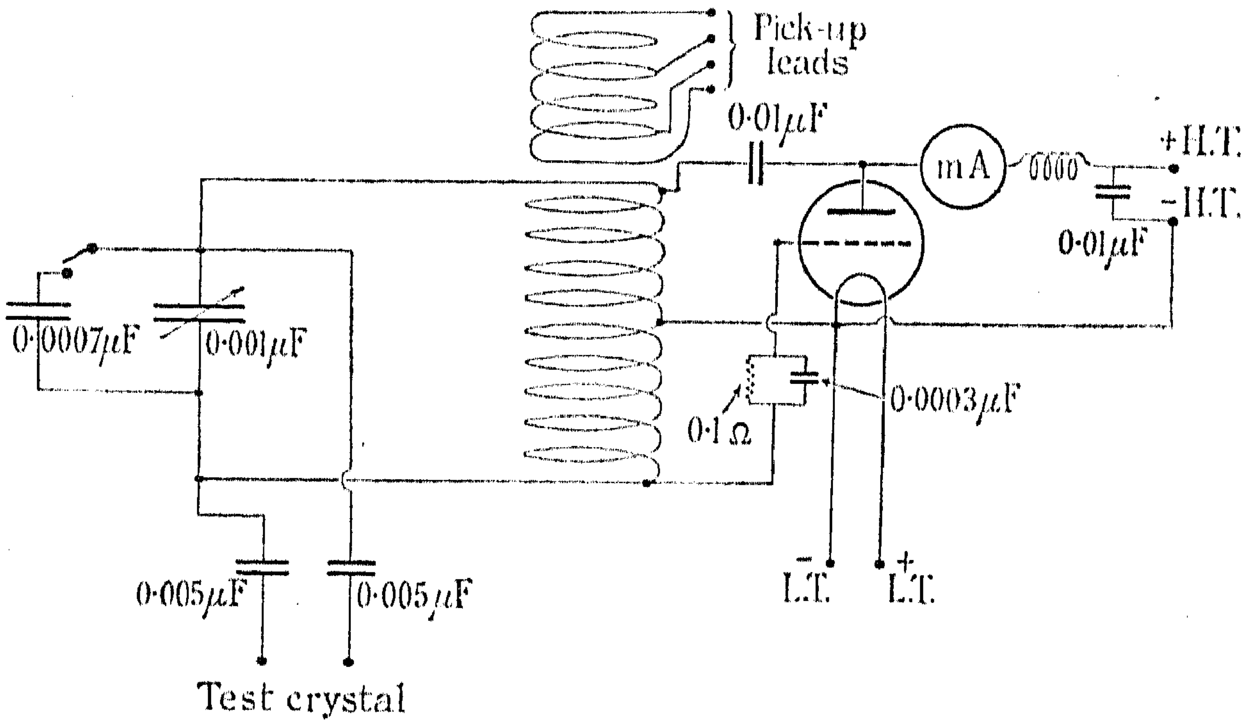


FIG. 7.—Absorption wavemeter.

Range 1.—6 000 to 9 000 m.
Range 2.—9 000 to 12 000 m.

From the point of view of reception, the latter of the above-mentioned transformers couples the piezo-electric element circuits to the line, while the first-mentioned couples the line to the grid circuit of the first valve of the amplifier. Thus the first-mentioned of these transformers is in fact triple-wound, one winding being a part of the excitation circuit, one being part of the line circuit, and the third being part of the grid circuit of the first valve of the amplifier.

In the highly resonant class of installation, such as the above-mentioned piezo-electric system working at supersonic frequency, the process of tuning is not very easy with the ordinary type of apparatus. All the circuits involved are of high inductance and low capacitance, and are not easily excited by the ordinary buzzer methods, and the high decrement both of the circuits and the wavemeter make accurate work both difficult and slow. This difficulty has been overcome by the use of absorption wavemeters of simple construction which allow rapid and accurate tuning to any reasonable degree of precision (see Figs. 7 and 8). The resonant circuits and the piezo-electric element itself (by virtue of its transfer of energy to the water) are fairly heavily damped, and to get good results the tuning must be carried out to well within 1 part in 100. With the absorption wavemeters mentioned above, tuning is perfectly easy to about 1 part in 400, when using an instrument such as can be carried round the dock side. If the scale is read with a vernier and if the absorption coupling is made variable so as to work at its optimum value, such an instrument can be read to 1 part in 1 000 (see Fig. 7).

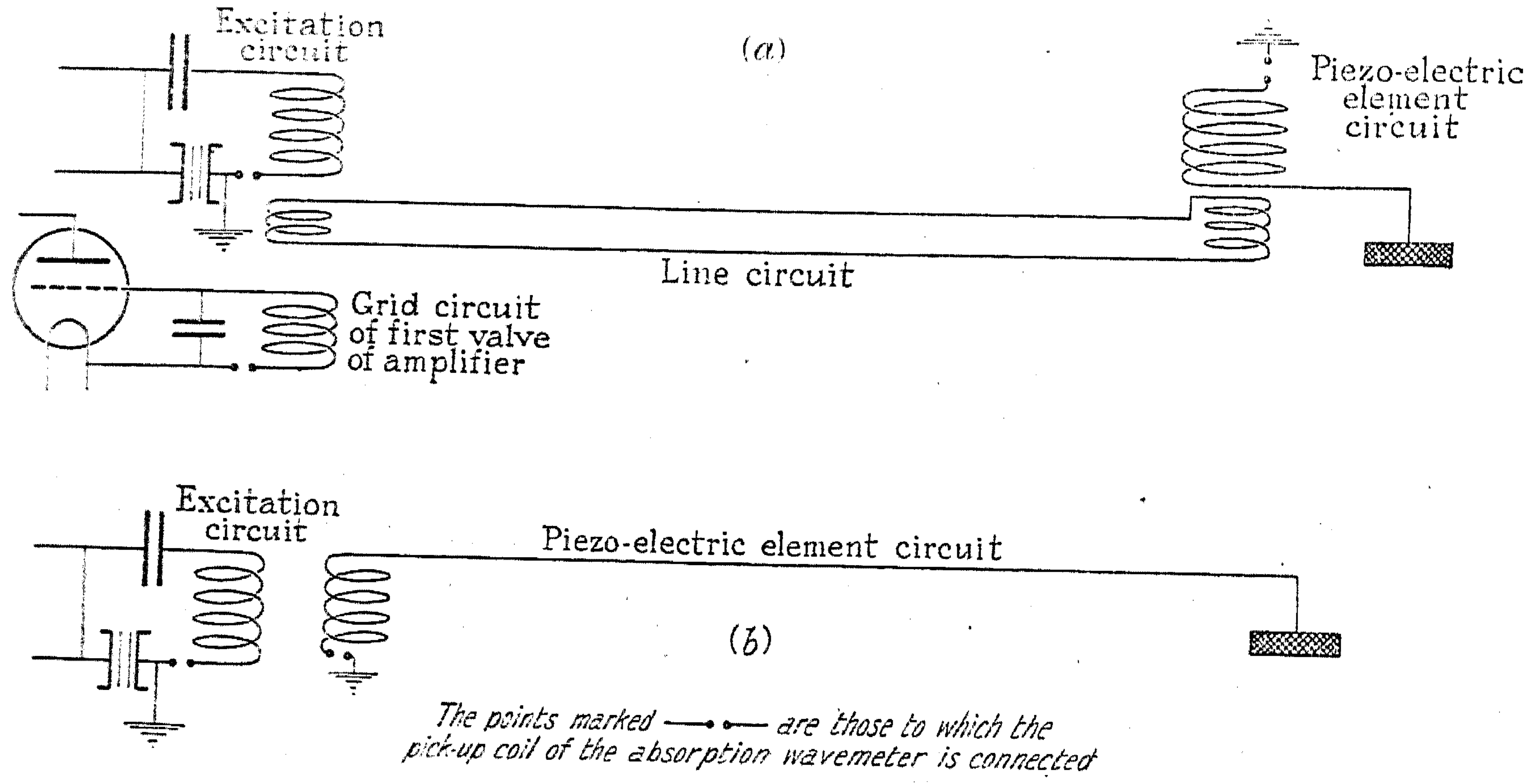
There is yet another method of sounding which should be mentioned, although it is not a "reflection" method. It consists of dropping overboard a small bomb which explodes on striking the bottom, and is designed to sink at a constant speed—approximately 1 fathom per sec. The time from letting go to hearing the explosion is taken by a stop-watch. A hydrophone receiver is usually employed.

(9) Application to Ice Detection.

The question arises as to why these methods of measuring the depth of water have not been applied commercially to the detection of ice or other floating bodies. The reasons are partly technical and partly commercial. Technically speaking a very great deal has been done, especially with resonant high-frequency directional apparatus, but the surface from which reflection has to be obtained is very limited. If it were only a case of searching for a large iceberg with its huge underwater body there would be every expectation of obtaining a reliable service, but a very thin sheet of floe ice may be the cause of a fatal accident, and in the present state of the art it is very difficult to make sure of a reliable service. To give nine ice warnings and fail at the tenth is not good enough.

Such a device could give three pieces of information, the presence of some unexpected obstruction, its bearing, and its distance. Of course, the two last-named include the former. The mechanism necessary to obtain such information fully automatically must be complicated, and therefore costly, and requires a vast amount of research in laboratories and subsequent sea-going experiment on a large scale before a reliable service can be obtained. Even if the information when obtained were always accurate, a great deal of experience is required before it could be stated that such a device would never miss a dangerous piece of ice.

Apparatus which is not fully automatic is not likely to appeal strongly to the British mercantile marine, because all people on board are fully occupied, and it is not as a general rule practicable to consider setting an additional human watch with a man or men having sufficient training to operate apparatus by direct observation.


Excitation circuit
(a)
Piezo-electric element circuit
Line circuit
Grid circuit of first valve of amplifier
Excitation circuit
Piezo-electric element circuit
(b)

The points marked —• •— are those to which the pick-up coil of the absorption wavemeter is connected

FIG. 8.

(a) Diagrammatic circuit of piezo-electric sounding system, with indirect connections, showing method of using the absorption wavemeter.
(b) Diagram of direct-connection installation.

The obvious method is to transmit directionally for a very short period, make a pause to allow for the return of the echo from any reasonable range, then alter the training of the transmitter and explore another sector in the same way.

There is also a possibility of transmitting continuously and trusting to interference effects to indicate the addition of a returning echo.

With high-frequency systems the most practicable method seems to be to rotate the transmitting element—which might also be the receiving element—about a vertical axis. For lower-frequency waves the alteration of training can be carried out by interference methods so as to avoid the mechanical movement of the apparatus.

(10) Application to Aeronautics.

The other fascinating field of development is to apply the reflection method to the determination of the height of aircraft above ground. Something has been done in this direction for lighter-than-air machines, but the problem does not seem very hopeful for heavier-than-air machines. The outstanding difficulty is the terrific noise-level. Even with the engines stopped the rush of air sets up a local noise-level which demands an extremely powerful echo. The author has not seen any frequency analysis of the clamour that exists in an aeroplane; there may possibly be some comparatively quiet spots in the low-frequency part of the audible spectrum, but an examination of the classic formulæ shows the hopelessness of working with high-frequency elastic waves in air.

APPENDIX.

The following useful and interesting formulæ have been collected from papers which have appeared in the *Hydrographic Review* of 1924 and 1925.

Absorption in Homogeneous Salt Water.

If d represents the distance from the source of origin at which the amplitude of the wave is reduced to 1/2·7183 of its original value, and if

λ = wavelength in water,
ρ = density of water,
v = rate of propagation of elastic waves in water,
μ = viscosity of water,

then
$$d = \frac{3v\rho}{\delta\pi^2} \times \frac{\lambda^2}{\mu}$$

In round numbers this represents, for average sea water, $2 \times 10^5 \times \lambda^2$, and hence we see that a wave of a frequency of 40 kilocycles per sec. is reduced by about one-third of its original amplitude due to absorption only after penetrating 30 km of homogeneous salt water. Such a wave would be similarly reduced in air after penetrating about 7 metres.

Spread of Cone from a Directional Transmitter.

If α is the angle between the wall of the cone and its axis, λ is the wavelength in water, and D the diameter of disc, then $\sin \alpha = 1 \cdot 2\, \lambda/D$. This cone should contain about 90 per cent of the energy radiated.

Pressure of Radiation.

If A = amplitude of displacement,
ω = pulsation of wave in water,
ρ = density of water,
v = velocity of propagation in water,
p = pressure of radiation,

then
$$p = \omega\rho v A$$

Power Emitted by Unit of Surface.

If P = power per unit of surface,
v = velocity of propagation,
ρ = density of medium,
p = pressure of radiation,

then
$$P = \frac{p^2}{2\rho v}$$

Therefore the amplitude of movement A of the surface for any power per unit of surface S is

$$A = \sqrt{\left(\frac{2P}{S\rho v\omega}\right)}$$

Thus for 1 watt per cm² and a frequency of 40 000 the amplitude is about 5×10^{-5} cm.

Discussion before the Wireless Section, 2nd December, 1931.

Prof. C. L. Fortescue: The device described in the paper was developed during the war period, but has been relatively slow in finding peace-time application. Very large sums are spent in providing extreme luxury in large modern ships and it is impossible not to feel that more money should be allocated to the development of installations of this kind, which add so greatly to the safety of travel by sea. Turning to the technical aspects of the paper, it appears that the oscillograph mirror in Fig. 3 should turn about an axis in the plane of the paper and that the spot of light would normally be just out of the observer's sight, only coming into view when the echo is received. With regard to the oscillator itself, it would be interesting to know whether the dimensions given in Fig. 4 are relatively correct, for the water would appear to constitute part of the load of the lower disc and the thickness of the two discs should therefore be somewhat different. Also, in the double oscillator, it would be interesting to know whether the two steel plates are cemented together in the middle or are merely pressed together mechanically; for if the latter is the case it seems that cementing the quartz to the steel should be unnecessary. In Fig. 5 what is termed a " line circuit " is used. In view of the wavelength—about 8 500 m—it seems probable that this circuit really acts as an untuned coupling. The author mentions the use of the sounding device in air, and though there are obvious difficulties it certainly seems that the method has many important applications, of which more may be heard later.

Commander G. C. Boles: The author claims to describe the present state of the art of sounding by reflection, but, unfortunately, economy of time and space has compelled him to give us a detailed description of only one type of echo-sounding device, and this particular system would appear to be open to various objections from the technical point of view. His description of the oscilloscope is interesting, but this type of instrument, which has hitherto been generally regarded as more suitable for laboratory work, appears to be hardly adapted for use under the rigorous conditions obtaining at sea. Do the size of the scale of the oscilloscope and the presence of the emission " kick " permit of accurate soundings being taken in shallow water, say 10 fathoms or less? They are certainly not easy to read on any part of the scale, owing to the fact that the constant flicking of a spot of light across the scale has a decided tendency to tire the eyes. Is not this system very inconvenient in that the oscilloscope, being operated by clockwork, has to be wound up with a key every few minutes? The author's claim to be able to tell the nature of the bottom of the sea by the shape of the top of the "kick" is interesting, and presumably a magnifying glass is required to reveal whether the top of the "kick" is serrated or flat. An existing type of indicator not mentioned by the author has an effective scale-length of about 3½ ft., as compared with the 12-in. scale of the oscilloscope. The soundings are shown by means of a red light against this scale and can easily be read to an accuracy of half a fathom in any depth of water. The author mentions that the counsel of perfection is to avoid docking the ship to install the transmitter. This can be arranged by suspending an emitter of the impact type in a ballast tank, and these are actually in use at the present time in many ships. This system does not require water under pressure: the emitter is simply suspended in the tank in free water, dry-docking of the ship therefore being unnecessary. The author states that a correction, which is easily made automatically, is necessary when using the "single impact" system to allow for the distance between the emitter and the receiver. This is not essential, as the correction can most easily be made by slightly compressing the graduations at the shallow end of the scale. The length of the base line only becomes material in shallow water of less than 40 fathoms. As regards the piezo-electric emitter shown in Figs. 4 and 6, does not the method of mounting introduce one of those pockets which collect air bubbles and which the author rightly regards as so very objectionable? The author states that in the directional beam system a 12° cone of radiated energy is sent out from the emitter. This would appear to mean that if the ship rolls more than 6° the echoes fail to return to the emitter, and soundings are therefore impossible. The same effect would be observed if the ship were on an even keel but the bottom of the sea sloped at 6° to the horizontal. It would be interesting to know how soundings are obtained under these conditions with the piezo-electric system, as it is obvious that soundings must be obtainable irrespective of the motion of the ship and whatever may be the rise and fall of the ocean bed. If the directional beam can be used for iceberg detection it will meet a long-felt and often-expressed need on the part of navigators. Certain experiments which were carried out in this direction, using one of the other forms of emitters, were abandoned because the density of the submerged part of the ice differs so little from that of the surrounding water that it was not found possible to rely upon getting an echo.

Captain J. W. S. Dorling: Echo sounding is one among many examples of the way in which the scientific man and the engineer have helped humanity and have enabled the sailor to carry on his calling more safely. Since the earliest times the sailor has always wanted to know, first, his position, and secondly, his course, his speed, and the depth of water under his keel. It is the last-mentioned which usually matters most in moments of crisis. The introduction of the chronometer and of wireless time-signals has made possible position-finding by astronomical observation, and wireless direction-finding has helped in the navigation of ships near the land. The gyro-compass and the electric log have helped in the determination of the actual course and speed through the water. None of these, however, can supersede sounding. Tides and currents may upset a dead reckoning, wireless direction-finding may be inaccurate or may not be available, and in a fog one cannot take sights, so that sounding is the mariner's greatest safeguard when he is approaching land or is in shallow water. Sailors have used various methods of sounding. They have used the pole and the hand lead, but naturally both are of limited application; one cannot sound with a pole over the side of the "Aquitania"! Lord Kelvin's sounding machine, which used a heavy lead with a piano-wire line and a graduated glass tube to give the depth of water, was one of the first improvements on the early methods. Now we have echo sounding, which has increased the depth we can sound and the speed through the water at which we can do it—both great advances. It is now possible, as the author states, to sound 100 fathoms at any speed and as often as we please, while still retaining accuracy at the shallow depths. The latter, of course, are very important, as at these depths there is only a small clearance between the bottom of the ship and the bed of the ocean. However, in spite of all the advantages of more modern methods, the practice of "swinging the lead" is still likely to continue, not only in H.M. ships, where it is the rule when entering harbour, but even in merchant ships and perhaps also in trawlers. One of the advantages of a lead is that if it does not find bottom when let out to a certain depth, one can be sure that there is no bottom within a distance corresponding to the length of the line let out; whereas if the electric sounding device gives no indication it is quite possible that it has gone out of action. From this point of view, it would be an advantage to extend the scale to 200 fathoms instead of stopping short at 100. Then, when approaching shallow water, one could start the machine and verify that it was working before it was really needed. On the other hand, this would reduce the accuracy at the shallow depths unless two scales and two operating speeds were provided. As regards receivers, the recording instrument has considerable advantages for some types of work. First of all, even if some of the echoes are missed the depth line will always be discernible. I have here a record made in a Norwegian fjord, and it shows the peaks and valleys in the sea bottom quite distinctly. A close inspection will reveal that at certain points the stylus has not marked the paper, but the general line of the bottom is clearly indicated. As in the case of other instruments such as aneroid barometers, a continuous record will often give more information than a series of individual readings. A record will show whether the soundings are shoaling gradually or suddenly, and will show up those sudden changes in depth which are often of value in fixing a ship's position; a record may be of especial value if a ship runs into fog unexpectedly. In the case of the optical machine, a man would have to be specially stationed at the machine to read the record every 5 minutes, or at whatever interval was chosen. For surveying, the recording machine is practically a necessity, and it cuts out a great deal of the old, laborious work of sounding and noting down times, depths, etc.

Captain F. G. Ramsay: I speak as a practical seaman, and not as an electrician or electrical engineer.

The conservative attitude of seamen to new inventions, such as those described by the author, is understandable in view of the hazardous nature of their work. If the engines break down with a wind on the lee shore, the ship may be lost. If the electric log or the hand log or other method of estimating the speed is wrong, and the navigator has really run 105 instead of 85 miles on a dark night towards the shore, his ship is inevitably lost. Echo sounding is what the seaman has been wanting for years, particularly for cable-laying work, in which direction I have been watching developments for the last three or four years. The first method was to drop a bomb to the bottom of the sea and measure with a stop watch the time which elapsed before the explosion was heard. The next great improvement was to employ oscilloscopes—first spots and later flashes of light being used to give the reading on the scale of the instrument. The Admiralty Mark VI sounding gear, which was fitted to the cable ships of the British Post Office a little over a year ago, is more satisfactory than any of the earlier types to which I have referred. (Captain Ramsay here exhibited a diagram.) This was taken 6 weeks ago, on a voyage from the Orkneys to the Irish Sea. The ship left Pentland Firth in fine weather, but a thick fog came on later and hung about for 24 hours. We had the echo-sounding gear going, and this diagram is the result. A precise knowledge of conditions at the sea bottom is very useful in cable-laying; for instance, if we were to lay a cable on the top of some of these cathedral-like heights it would not last long. This sounding gear has been in constant use for over 12 months, and all the attention it has had has been a few drops of oil on the motor. If the gear is to be satisfactory from the seaman's point of view it must comply with certain conditions. It must be reliable, and sufficiently simple in operation to be worked by the officer of the watch. A type of gear which requires a highly-paid and efficient technician to operate it, is of no use to an ordinary merchant ship, tramp steamer, or trawler. The Mark VI gear is of the recording type, but it can also be used with head-phones if the recording part breaks down. The depth can be estimated more accurately with the head-phones than with the recording gear. In 21 ft. of water one can, with practice, read the depth to within 3 in. with head-phones, whilst with the recording gear the depth can be obtained to within half a fathom if everything is correctly adjusted. In confirmation of my figure of 3 in. for the minimum error of the gear when measuring a depth of 21 ft., the Port of London harbourmaster told me a short time ago that this type of gear is being regularly used in conjunction with the hand lead for surveying the Thames estuary, and that when a difference of 6 in. between the two readings is obtained the sounding-gear figure is accepted. It is very easy to make sure that the gear is correctly adjusted, particularly on a cable ship, which is constantly at work while tied up to a cable. When the ship is at rest in 30 to 50 fathoms of water the depth is measured first with the hand lead, secondly with the Kelvin sounding gear, and finally with the echo-sounding machine. Agreement between the results indicates that the latter is in order.

Mr. B. S. Smith: Echo sounding appears at first sight to be rather a roundabout method for determining the depth of water, and it naturally does not appeal to the sailor at the outset. For this reason it is interesting to learn that the surveying services have been responsible for bringing echo sounding to its present state. The surveyors created the demand for echo apparatus and insisted on the development of echo methods. They were naturally the first to put these methods to practical use. Echo sounding is now a well-established method for surveying depths between 10 and 100 fathoms, and by its use the area which can be surveyed in a given time has been about doubled. A problem in connection with surveying which has not been finally solved is that of finding the depth of shoal water when this is too shallow for the surveying ship to enter. Such work has to be done at present by motor-boats, and it occupies a large proportion of the total time. Experiments are being made with a view to the fitting of sounding gear to motor-boats. Turning to ordinary navigational uses, echo sounding has greatly increased the use of soundings by ships. In the ordinary way the sailor confines his soundings to times when he expects to approach a well-known ridge, or when he knows he is running towards shoal water. Echo-sounding gear, however, will enable him to find his position at any time simply by comparing his soundings with those given on the chart. The great advantage of echo sounding is that it gives a series of readings rapidly, even when the ship is moving at full speed, and from these readings a mean sounding can be obtained. Echo-sounding records have actually been taken at a speed of 30 knots, and possibly even faster. The paper is inclined to give the impression that echo sounding depends for its action upon laboratory apparatus. It will be agreed, however, that it can be and is carried out with very simple gear, such as a spring-driven emitter, an ordinary microphone, and a pair of head-phones. The very simple aural method involves the minimum of apparatus. The need for simple apparatus, particularly in the early stages of development, is very important, because if the sounding gear goes wrong the navigator will get tired of it. It is undoubtedly a difficult problem to make gear of this character which will work well under sea conditions. As regards the relative advantages of the use of high and lower frequencies, I consider that troubles due to the disturbed water under the ship are considerably increased by the use of a high frequency. The absorption effects are considerably greater at a frequency of nearly 40 kilocycles per second than they would be at 1 500 cycles per second. Has the author any information on this point? The directional emitter is rather a mixed blessing, if it is a blessing at all. On the other hand, the essence of the sonic system is to provide screening between the emitter and the receiver, so that the direct sound from the emitter does not reach the hydrophone. This is a difficult matter, and suitable positions have been found only as the result of experiment and experience. Undoubtedly the separation which is necessary is a disadvantage, but I should like to ask whether the use of the same instrument for emission and reception enables reliable soundings to be obtained in very shallow water. Fig. 8 seems to indicate that the high transmitting voltage is applied directly across the valve. In such circumstances, would the valve have recovered and the strong local reverberations occurring immediately afterwards have died down sufficiently rapidly to enable one to pick up the echo in very shallow water?

Dr. E. H. Rayner (*communicated*): It would be of interest to have more details concerning the construction of the quartz generators shown in Fig. 3. They are loaded with metal plates, and the inertia forces tending to separate the plates from the quartz must be very considerable, in view of the fact that the inertia forces set up when unloaded quartz is used may be sufficient to disrupt it. Possibly an initial compression on the system might be useful to prevent the cement joint from giving way. There is, of course, the very considerable dynamic loading due to the water, which may greatly modify the conditions compared with the use of free quartz. Is any information available as to the value of the forces at the metal-water interface at 37 kilocycles per second? One would expect that there would be risk of cavitation; but perhaps the tensile strength of water at such frequencies is very considerable. It might be expected to fall off at lower frequencies, and the presence of a relatively small quantity of air bubbles might afford a good excuse for a condition of semi-cavitation to arise, so that the adverse influence of bubbles might be serious at the interface as well as in the general bulk of the water.

Commander J. A. Slee (*in reply*): For Prof. Fortescue's information I would say that the dimensions given in Fig. 4 are approximately correct. No adhesive is used between the lower face of the active triplet (in the lower part of Fig. 4) and the upper face of the plug in contact with the water. The usual practice is to oil the surfaces and then screw down firmly on the upper collar. The question of cement does not arise. In the active triplet the whole oscillates as one and close adhesion between quartz and steel is necessary, but the outer plug shown in the lower part of the figure has nothing to do with the frequency of the oscillation. It is only a means of protecting the active triplet from injury, the vibrations of emission and reception passing through the plug without alteration of frequency.

In answer to Commander Boles's questions, the oscilloscope is by no means a laboratory instrument. Over 200 of this pattern are in use in the mercantile marines of the world, and no trouble has been experienced with them. There is no difficulty in reading a sounding with 3 fathoms of water under keel when using the 360-fathom scale, or about half this with the 160-fathom scale. It is quite a mistake to suppose either that the instrument is difficult to read or that it is tiring to the eyes. All kinds of seagoing persons read it at once and with ease, from the captain of a first-class liner to the deck-hand of a trawler. No inconvenience has been encountered in practice due to the clockwork motor. When a sounding is wanted the instrument is started, and when the sounding has been read it is stopped. Magnifying glasses are not used for the purpose of reading the scale. With regard to air collecting in the pocket between the projector and its housing, the air is, of course, harmless as long as it is not in contact with the projector face. It is usual to keep the space surrounding the projector free from air by means of a vent pipe. The transmitted cone has not sharply-defined edges and the bottom of the sea is not a mirror surface. As a result, only very heavy rolling will prevent an echo from returning, and even then only momentarily. The slope of the sea bed makes but little difference. As stated in the paper, the difference between good and bad conditions may cause a variation of from 1 to 10 times in the received energy at any given depth, but the amplification available is sufficient to provide for this contingency.

Replying to Mr. Smith, commercial apparatus now exists in France for use in, or slung over the side of, surveying launches, and it is believed that it has proved very successful. A statement has been made that a surveying vessel with reflection-sounding apparatus and a recorder was able to cover five times as great an area in a given time as had been possible with hand apparatus. With reference to the rate of absorption at different frequencies in "solid" water, the formula in the Appendix is believed to be beyond dispute. On the subject of water full of bubbles, no precise information is available. With apparatus of the type described, the amplifier recovers sufficiently quickly to allow the very robust reflecting galvanometer in use to give a perfectly clear indication with 3 fathoms of water under keel, even when using the full transmission voltage. The amount of amplification is necessarily adjustable, and for this depth it should be reduced to its working minimum. Persons accustomed to the instrument can identify the return peak with 2 fathoms under keel. These figures apply to the standard trawler instrument, reading up to 360 fathoms. With a more open scale the shallow readings are roughly in proportion.

As regards Dr. Rayner's remarks, in the commercial types of apparatus the amplitude of the vibration of the surface of the outer plate is so small that there appears to be no risk of cavitation. There is no doubt that a layer of minute air-bubbles in contact with the face of the projector has a serious effect on both emission and reception. Fortunately this condition does not seem to arise in ships under way.

ERRORS IN POWER-FACTOR MEASUREMENT DUE TO TERMINAL LOSSES ON SHORT LENGTHS OF CABLE.*

By R. A. BROCKBANK, B.Sc., Associate Member.

(*Paper received 4th August*, 1931.)

SUMMARY.

It is frequently necessary for economic reasons to carry out tests on short cable samples. Measurements of a.c. leakance and power factor on short lengths of power or submarine cables may be subject to considerable error unless due allowance is made for end effects, which are of minor importance on long lengths. The application of the simple guard wire, which is adequate for d.c. testing, is not sufficient to secure accurate results. The nature of the errors which arise is discussed, a theory of the cause of the errors is developed, and recommendations are made as to the form of guard which will enable accurate results to be obtained.

(1) INTRODUCTION.

It has frequently been observed that in short (e.g. 5-ft.) samples of power cable the measured power factor may be two or three times the true value of the dielectric power factor as determined on long lengths (e.g. 100 yards or more) of the same cable, and it follows, therefore, that the somewhat empirical and varied methods of guarding often adopted may lead to considerable errors. The work described here was carried out with a view to investigating the mechanism of this phenomenon, and to developing satisfactory methods of testing such short lengths of cable.

The problem of determining the power factors of short (e.g. 20-ft.) lengths of submarine-cable samples involves the elimination of a variable end effect which leads to very different power factors being obtained from day to day. This problem appears to be closely allied to that of the power cable, merely involving different magnitudes, and it has therefore been studied here. Experiments carried out on submarine cables have yielded valuable data bearing upon the end-loss problem, and some of these experiments are described below.

The problem was first investigated experimentally and then a theory was developed to fit the observed facts. This paper describes the progress of the work, and concludes with recommendations for testing various types of cables.

(2) EXPERIMENTAL.

General.

In both low-voltage and high-voltage d.c. insulation testing the Price guard wire applied round the end of the insulated core gives satisfactory results even when the surface leakage over the ends is of a high order. For high-voltage testing additional precautions against pick-up of corona or ionization currents from the high-voltage line have to be taken by enclosing the whole cable sheath in an earthed cage.

Turning now to a.c. testing, we have still to obtain the same condition, viz. the only current which passes through the measuring circuit (R_3 resistance arm of a Schering bridge, or current coil of a wattmeter) must flow through the dielectric between the two test electrodes (core and sheath) within the cable cylinder bounded by the outside sheath. Preliminary tests bore out the anticipated result that on power cables the direct surface leakage over the dielectric from core to sheath was entirely negligible on even the shortest end (3 inches). If this is coupled with the fact that the effective resistance of the cable under alternating current is considerably less than 1 per cent of the d.c. resistance, it is apparent that the loss from this cause is infinitesimal and cannot account for the magnitude of the total loss observed. The use of a Price guard wire for the normal purpose of preventing surface leakage over the end of the core therefore appears to be redundant.

As previous experience had indicated, however, that a reduction in power factor could be obtained by the use of a guard ring, a series of tests was made on short lengths of cable with different types and positions of guard rings. Among the types investigated were several turns of binding wire, the Dieterle lead sleeve, and lead foil.

Effect of Guard-Ring Spacing.

TABLE 1.

Power Factor of 6-ft. Length of Guarded Cable, at 50 Cycles per Second.

Volts	Guards $\frac{1}{16}$ in. from sheath	Guards $1\frac{1}{2}$ in. from sheath	Guards $2\frac{3}{4}$ in. from sheath	No guards
1 500	0·0053	0·0071	0·0075	0·0080
3 000	0·0057	0·0083	0·0085	0·0087
4 000	0·0065	—	—	—
5 000	0·0065	0·0094	0·0095	0·0097

Table 1 and Fig. 1 show the effect of a $\frac{1}{2}$-in. width lead-foil guard wrapped tightly round the core of a 6-ft. length of cable (0·040 in. paper thickness).† Most of the early experimental work was carried out on power cables, the end-loss problem of which required an immediate solution.

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* The Papers Committee invite written communications, for consideration with a view to publication, on papers published in the *Journal* without being read at a meeting. Communications (except those from abroad) should reach the Secretary of the Institution not later than one month after publication of the paper to which they relate.

† For a further reference to some of these tests, see T. N. RILEY and T. R. SCOTT: "Insulating Oils for High-Voltage Cables," *Journal I.E.E.*, 1928, vol. 66, p. 828.

Fig. 1 shows that the end loss increases rapidly for even small guard separations, particularly at high voltages. By producing these curves back to the ordinate one may show that with an infinitely close guard the power factors agree very closely at all voltages, as was to be expected from results obtained on longer lengths.

The small discrepancies with the low voltage appeared to indicate that the loss was due to a voltage phenomenon, and would accordingly disappear at lower voltages. Similar tests were therefore made at 800 cycles per sec. on a similar cable at about 40 volts. The results are shown in Table 2.

TABLE 2.

Power Factor of 6-ft. Length of Guarded Cable, at 800 Cycles per Second, 40 Volts.

	Close guards	Guards ½ in. from sheath	No guards
	0·00426	0·00483	0·00492
Percentage increase ..	—	13	15

The end loss is in evidence even in this case, but shows a smaller increase with, however, a steeper initial rise. The results obtained from further tests indicated that the loss occurred at the edge of the ends of the sheath, and was apparently a function of the length of edge.

Determination of the Effective Surface Resistance.

In order to obtain quantitative values for the leakage resistance from the edges of the sheath, the effect of the end loss was multiplied in the following way. Six feet of 0·15-sq. in. copper strand was lapped with 35 5-mil papers and an outer metallized paper. The core was dried and impregnated, and the power factor measured. The metallized paper was then removed and open helices of 0·036-in. tinned copper wire with different pitches were wound on the core between two fixed points 61 in. apart. With each disposition of the wire, the power factor and capacitance were measured at 50 cycles per sec., 2 000 volts, and 800 cycles per sec., 40 volts. From these results (shown in Table 3) it was possible to deduce the leakance contributed by each unit length of wire edge acting over a length of core equal to half the pitch of the wire helix. Figs. 2 and 3 show these leakances plotted against half the pitch of the wire. The curves corroborate the previous qualitative tests, indicating that the loss per unit length along the core is very intense near the edge of the sheath, but decreases rapidly and becomes almost nil at distances of about 3 to 5 in. from the edge of the sheath. These tests assumed that the surface characteristics of the core did not change during the course of the experiment, but, as the loss would appear to be largely bound up with a surface effect, the electrical characteristics of the surface and body of the dielectric would be of great importance. The surface resistivity is a factor which appears to be capable of great variability: the value on a freshly opened core is much higher than on a core which has been left open to the atmosphere for some time and on which a moisture

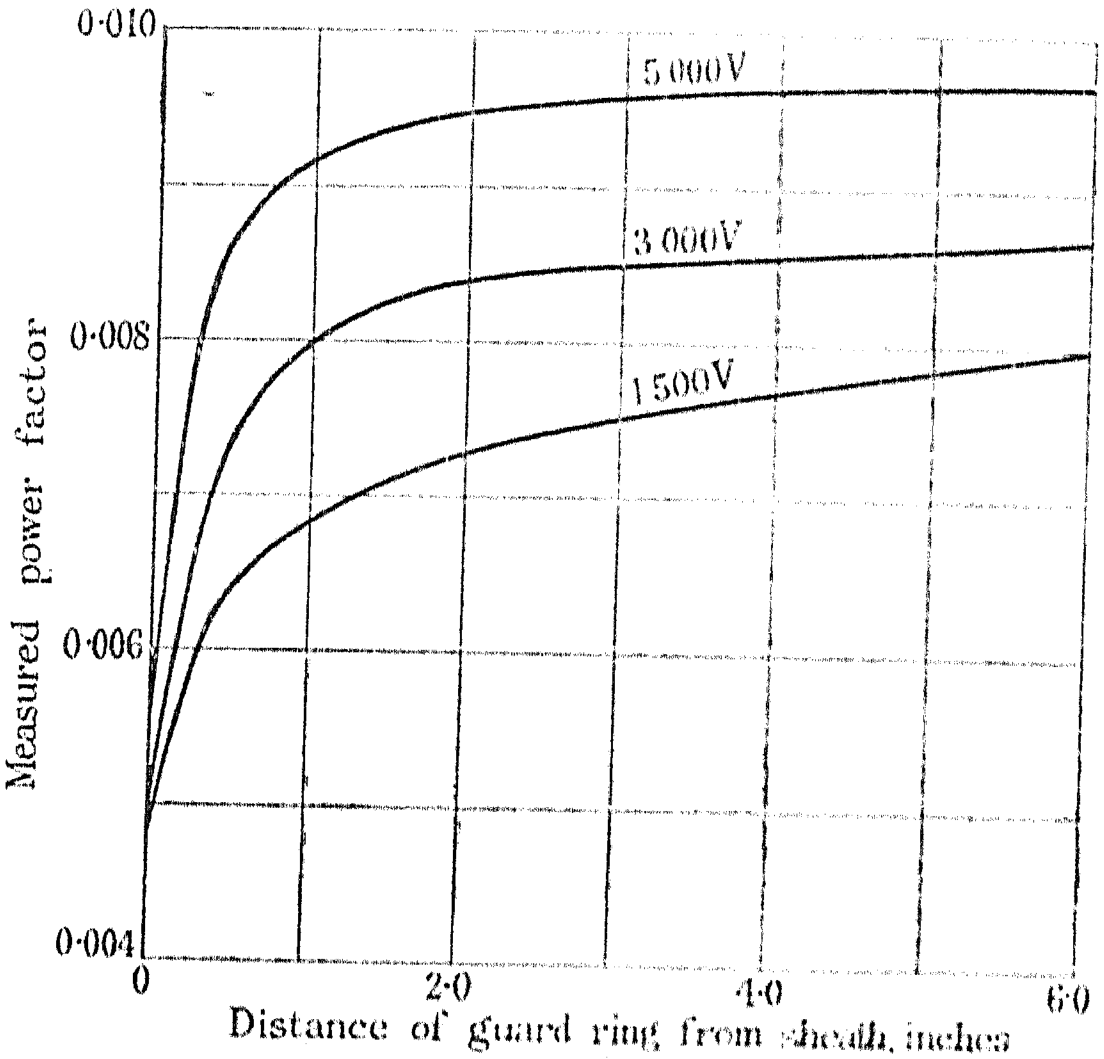

FIG. 1.—Variation of power factor with guard-ring spacing.

TABLE 3.

Turns of wire	Spacing (pitch), inches	Length of wire, inches	50 cycles per sec., 2 000 volts			800 cycles per sec., 40 volts		
			Measured power factor	Leakance, units	Leakance per unit length of wire	Measured power factor	Leakance, units	Leakance per unit length of wire
	completely covered		0·0050	—	—	—	—	—
476	0·125	1 336	0·048	20	0·015	0·014	5·6	0·0042
238	0·251	663	0·095	36	0·054	0·022	7·6	0·0114
119	0·51	334	0·174	58	0·174	—	9·7	0·029
56	1·09	164	0·325	73	0·445	0·059	11·1	0·068
13½	4·5	71	0·42	57	0·804	0·100	12·4	0·174

film will have condensed and been absorbed by the outer paper.

Variation of End Loss With State of Core Surface.

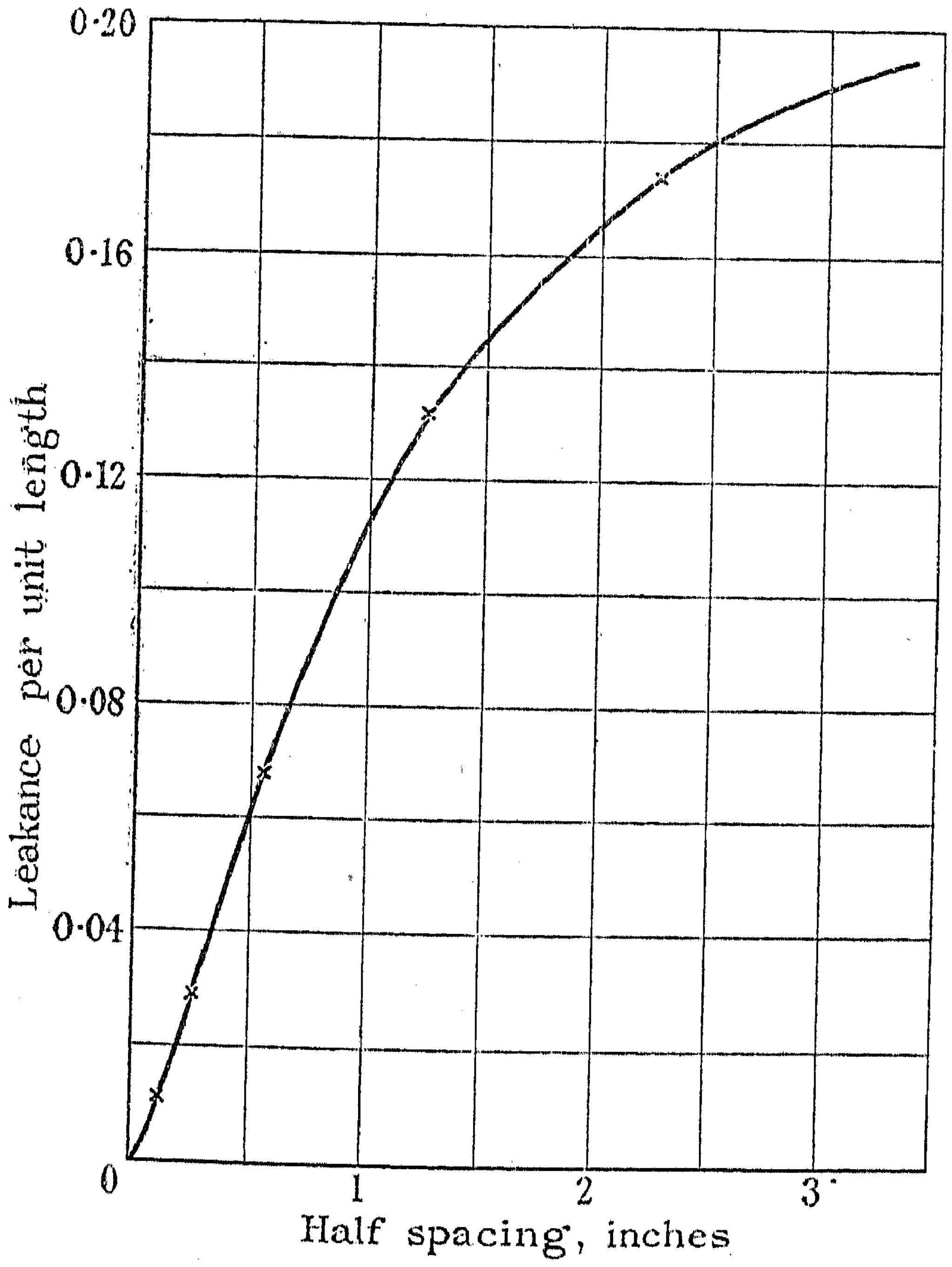

FIG. 2.—Leakance per unit length at 800 cycles per second, with various spacings.

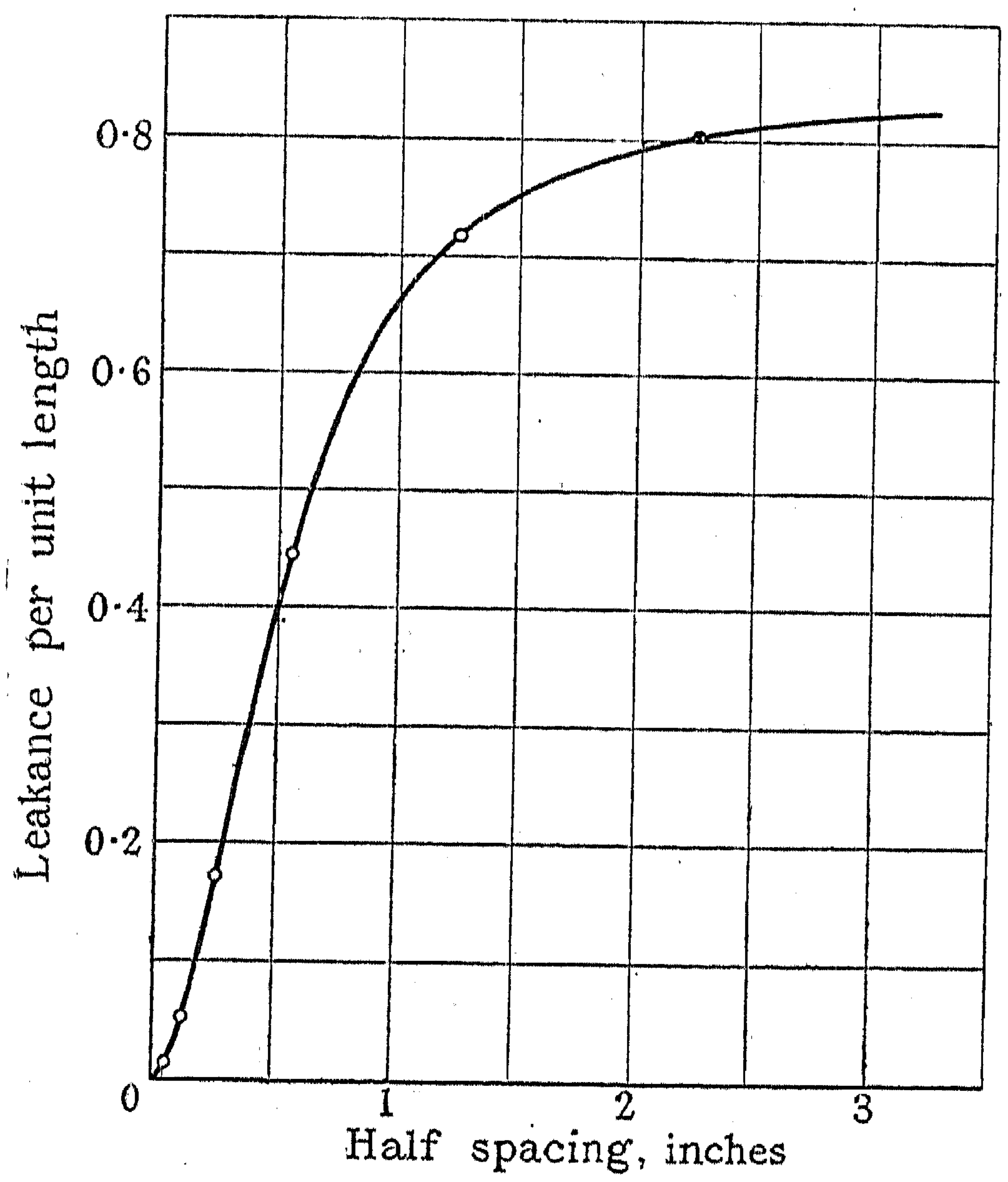

FIG. 3.—Leakance per unit length at 50 cycles per second, with various spacings.

TABLE 4.

Test	Time	Voltage	Power factor
After impregnation, both papers on	0	volts 2 000	0·0039
		5 000	0·0039
Outer paper off	3 mins.	2 000	0·0042
		5 000	0·0083
	2 hours	2 000	0·0051
		5 000	0·0268
	4 ,,	2 000	0·0055
		5 000	0·0334
	5½ ,,	2 000	0·0058
		5 000	0·0365
	26 ,,	2 000	0·0091
		5 000	0·047
	50 ,,	2 000	0·0115
		5 000	0·045
	70 ,,	2 000	0·0112
		5 000	0·0464
After a week-end of high relative humidity	120 ,,	2 000	0·0264
		5 000	0·059
Core passed through steam	0	2 000	0·0292
		5 000	0·0345
	3 mins.	5 000	0·0404
	5 ,,	5 000	0·0437
	10 ,,	5 000	0·0500
	12 ,,	2 000	0·0472
	20 ,,	2 000	0·0544
	22 ,,	5 000	0·0593
	50 ,,	5 000	0·0728
	52 ,,	2 000	0·0638
	105 ,,	5 000	0·0810
	106 ,,	2 000	0·0632
	240 ,,	5 000	0·086
		2 000	0·0648
Water rubbed over core		5 000	0·0305
		2 000	0·0279 rising

In order to determine approximately the extent to which the end loss is dependent on the atmospheric conditions and the state of the core surface, the following experiment was conducted. A short sample of cable (0·11-in. dielectric thickness) was lapped with two metallized papers, the lower being an open helix with a gap of 0·6 in. and the upper a similar helix to cover the lower gap. The cable was impregnated and a power-factor reading taken on the completely covered core. The outer paper was then stripped and another reading taken immediately. Readings were continued after various intervals of time (Table 4), the voltage being removed during the intervals. Ultimately the readings were found to become approximately constant at a value settled by the atmospheric conditions. The results, plotted in Fig. 4, indicate that the core is extremely sensitive to atmospheric changes in humidity, etc., and that a period of 30 to 50 hours is required for the power factor to rise to a stable value under normal air conditions. The cable was next passed through a jet of steam and readings taken immediately and at various intervals of time as the moisture dried off. Finally, the core was rubbed with a wet rag and again measured. It would appear that for a particular set of conditions there exists a definite surface resistance which will produce a maximum loss at the ends. This is shown diagrammatically

TABLE 5.

Guard-Ring Experiments on 66 kV Cable. Power-Factor Tests Under Various Conditions.

Cable	⅜-in. close guard			1-in. close guard			1-in. guard, ½-in. spacing			1-in. guard, 1-in. spacing		
	Power factor (per cent) at			Power factor (per cent) at			Power factor (per cent) at			Power factor (per cent) at		
	10 kV	27 kV	47 kV	10 kV	27 kV	47 kV	10 kV	27 kV	47 kV	10 kV	27 kV	47 kV
2-ft. cable, 3-ft. ends, fresh ends	—	—	—	0·465	0·433	0·451	0·455	0·56	0·57	—	—	—
2-ft. cable, 3-ft. ends, after 24 hours	—	—	—	0·445	0·407	0·385	—	—	—	—	—	—
2-ft. cable, 3-ft. ends, after 48 hours	—	—	—	0·38	0·39	0·38	0·45	0·50	0·49	—	—	—
2-ft. cable, 1-ft. ends	—	—	—	0·35	0·39	0·45	0·43	0·56	0·60	—	—	—
3-ft. cable, 3-ft. ends	—	—	—	0·48	0·41	0·38	0·52	0·45	0·43	0·52	0·62	0·60
3-ft. cable, 3-ft. ends, after 24 hours	0·36	0·34	0·34	0·37	0·38	0·37	0·38	0·42	0·42	0·66	0·65	0·59
3-ft. cable, 3-ft. ends, after 48 hours	1·44	0·43	0·42	—	—	—	0·49	0·50	0·53	0·59	0·72	0·75

TABLE 5—*continued.*

Cable	1-in. guard, 1½-in. spacing			1-in. guard, 2-in. spacing			1-in. guard, 4-in. spacing			1-in. guard, 8-in. spacing		
	Power factor (per cent) at			Power factor (per cent) at			Power factor (per cent) at			Power factor (per cent) at		
	10 kV	27 kV	47 kV	10 kV	27 kV	47 kV	10 kV	27 kV	47 kV	10 kV	27 kV	47 kV
2-ft. cable, 3-ft. ends, fresh ends	0·465	1·06	1·10	—	—	—	—	—	—	—	—	—
2-ft. cable, 3-ft. ends, after 24 hours	—	—	—	—	—	—	—	—	—	—	—	—
2-ft. cable, 3-ft. ends, after 48 hours	0·63	1·13	1·19	—	—	—	—	—	—	—	—	—
2-ft. cable, 1-ft. ends	0·58	1 08	1·16	—	—	—	—	—	—	—	—	—
3-ft. cable, 3-ft. ends	—	—	—	0·56	1·07	1·19	0·65	1·56	2·28	0·66	1·64	3·45
3-ft. cable, 3-ft. ends, after 24 hours	—	—	—	1·21	1·27	1·16	2·10	2·61	2·89	2·11	2·77	3·87
3-ft. cable, 3-ft. ends, after 48 hours	—	—	—	0·89	1·31	1·30	1·17	2·04	2·30	1·13	1·92	2·36

TABLE 5—*continued.*

Cable	$\frac{1}{16}$-in. spacing, wire guard			No guard			$\frac{1}{16}$-in. spacing, 2-in. guard			$\frac{1}{16}$-in. spacing, 4-in. guard			$\frac{1}{16}$-in. spacing, 8-in. guard		
	Power factor (per cent) at			Power factor (per cent) at			Power factor (per cent) at			Power factor (per cent) at			Power factor (per cent) at		
	10 kV	27 kV	47 kV	10 kV	27 kV	47 kV	10 kV	27 kV	47 kV	10 kV	27 kV	47 kV	10 kV	27 kV	47 kV
2-ft. cable, 3-ft. ends, fresh ends	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
2-ft. cable, 3-ft. ends, after 24 hours	0·40	0·19	0·31	—	—	—	0·440	0·43	0·39	0·443	0·44	0·41	0·44	0·44	0·42
2-ft. cable, 3-ft. ends, after 48 hours	0·10	0·12	0·25	0·81	2·2	6·0	—	—	—	0·40	0·41	0·41	—	—	—
2-ft. cable, 1-ft. ends	—	—	—	0·76	2·2	6·2	—	—	—	0·37	0·43	0·48	—	—	—
3-ft. cable, 3-ft. ends	—	—	—	0·68	1·73	4·09	—	—	—	—	—	—	—	—	—
3-ft. cable, 3-ft. ends, after 24 hours	—	—	—	1·95	2·67	3·96	0·40	0·40	0·39	0·42	0·42	0·41	0·43	0·43	0·42
3-ft. cable, 3-ft. ends, after 48 hours	0·93	1·94	3·3	1·16	2·13	2·93	—	—	—	—	—	—	—	—	—

in Fig. 5, where a purely arbitrary scale is chosen for the unknown magnitude of the effective surface resistance of the core.

Tests on Full-Size Power Cables at High Voltages.

All the experiments up to this stage had been conducted at relatively low voltages on small cable samples having a low insulation thickness. The tests were now extended to cover full-size power cables at high voltages where sparking, ionization, etc., on the core might considerably modify the effects. It was also desired to obtain an idea of the accuracy with which the power factor of very short cable lengths could be measured and of the relative efficiency of various types of guard connections. For this purpose, the following type of cable was chosen:—

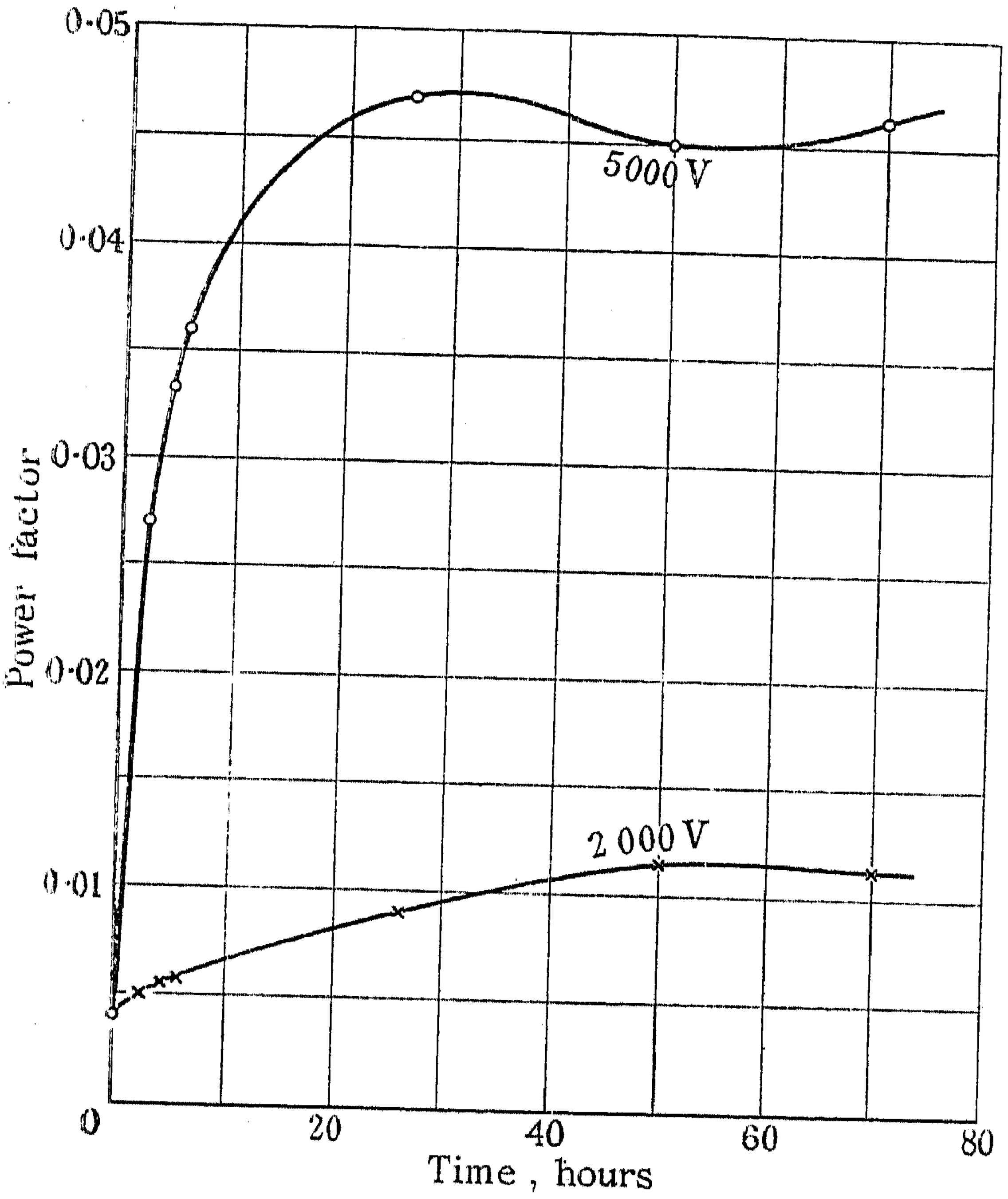

FIG. 4.—Variation of power factor with time.

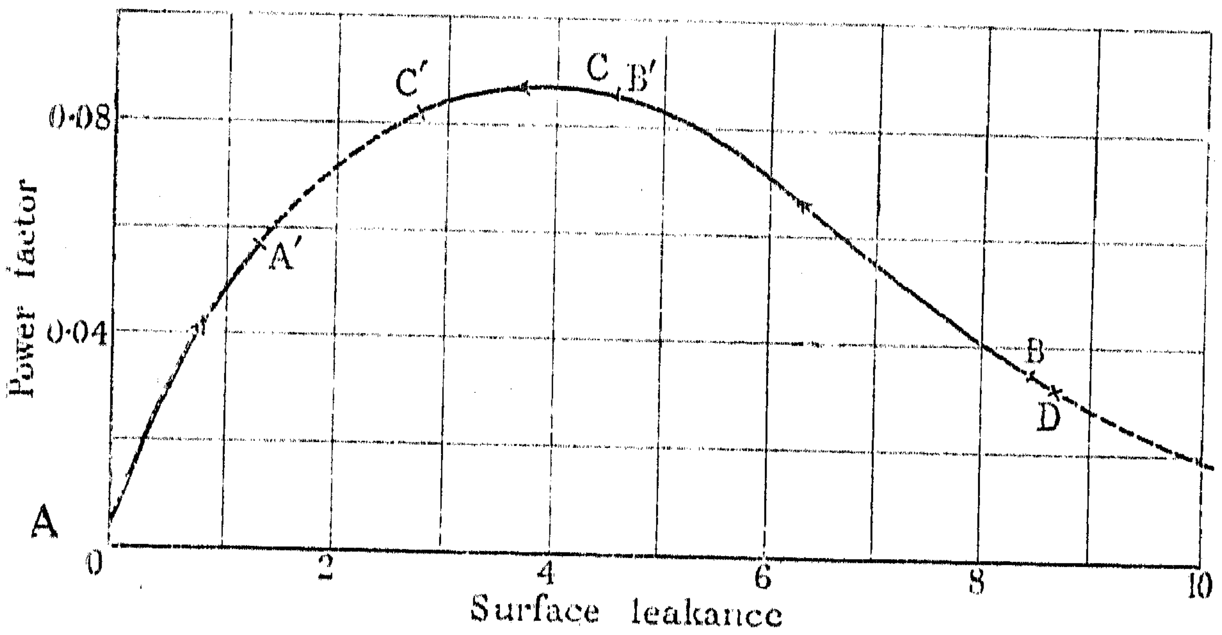

FIG. 5.—Variation of power factor with surface leakance.

AA′.—Initial rise of power factor with time. Steady at A′ at atmospheric humidity.
BB′.—Passed through steam jet. Drying curve in atmosphere.
CC′.—Artificial drying.
D.—Core rubbed with water.

0·2-sq. in., single-core, 66-kV (38 kV to earth), lead-sheathed " Hochstädter " cable.

Thickness of dielectric = 0·55 in.
Diameter over dielectric = 1·67 ,,
Thickness of lead = 0·12 ,,

As the variation in power factor due to the end loss will be more pronounced the shorter the length of cable, tests were conducted with cable lengths of 2 ft. and 3 ft. (length of sheath) and ends varying from 1 ft. to 3 ft. in length.

The Schering-bridge method of measurement was used throughout and voltages up to 50 kV were applied, at which value considerable sparking occurred along the core at the guard ring. The bridge was carefully shielded, and in all cases the lead sheath was protected from " pick up " from the h.t. leads by enclosing it in an envelope of metallized paper connected to earth.

Preliminary tests showed that under certain conditions of guard-ring spacing and voltage the measured power factor was very much lower than the true value for the dielectric (values of less than 0·001 were obtained). In order to ascertain whether the small difference of potential between the earthed guard-ring and the lead sheath was not the cause of this anomalous behaviour, a circuit consisting of a parallel resistance and capacitance was included in the earthed lead of the guard-ring, and the potential of the guard was adjusted to that of the lead sheath. This refinement had no effect, however, and the fact still remains that certain quite usual methods of guarding can produce a considerable drop in the apparent power factor of the cable. The most satisfactory explanation of this phenomenon is given later.

The material used for the guard was in most cases $\frac{3}{4}$-in. or 1-in. wide lead-foil tape which was wrapped tightly round the core and bound up with 0·024-in. binding wire. For certain tests metallized paper or an ordinary wire guard were employed:—

The tests may be roughly divided into two parts:—

(*a*) Variation of the measured power factor with increase in spacing between the sheath and guard ring.
(*b*) Variation of the measured power factor with length of guard ring.

An examination of Table 5, which summarizes the results of the tests, reveals the following points:—

(i) With a 1-in. wide close guard the power factor is fairly steady in most cases, but there is a quite definite tendency for the power factor to fall with increasing voltage, particularly with fresh ends.

(ii) Increasing the separation between the sheath and guard ring causes an increase in the power factor, the previous decrease with voltage now changing to a more or less rapid rise with voltage.

(iii) The experiment of placing a wire guard-ring close to the sheath shows that the apparent power factor may vary enormously and erratically with the voltage and the time of opening-up of the core.

(iv) A long guard (4 to 8 inches) placed close to the sheath is required in order to obtain uniform results, and this arrangement apparently yields the true power factor of the cable, as the value it gives is in good agreement with that obtained on the complete cable length.

The variation of power factor with spacing for a 1-in. wide guard ring is shown in Fig. 6. The cable was 3 ft. long, had 3-ft. ends, and had been open to the atmosphere for 24 hours.

The series of tests, described above, on the cable with plain ends could not be extended beyond 50 kV owing to the severe sparking which occurred with higher voltages.

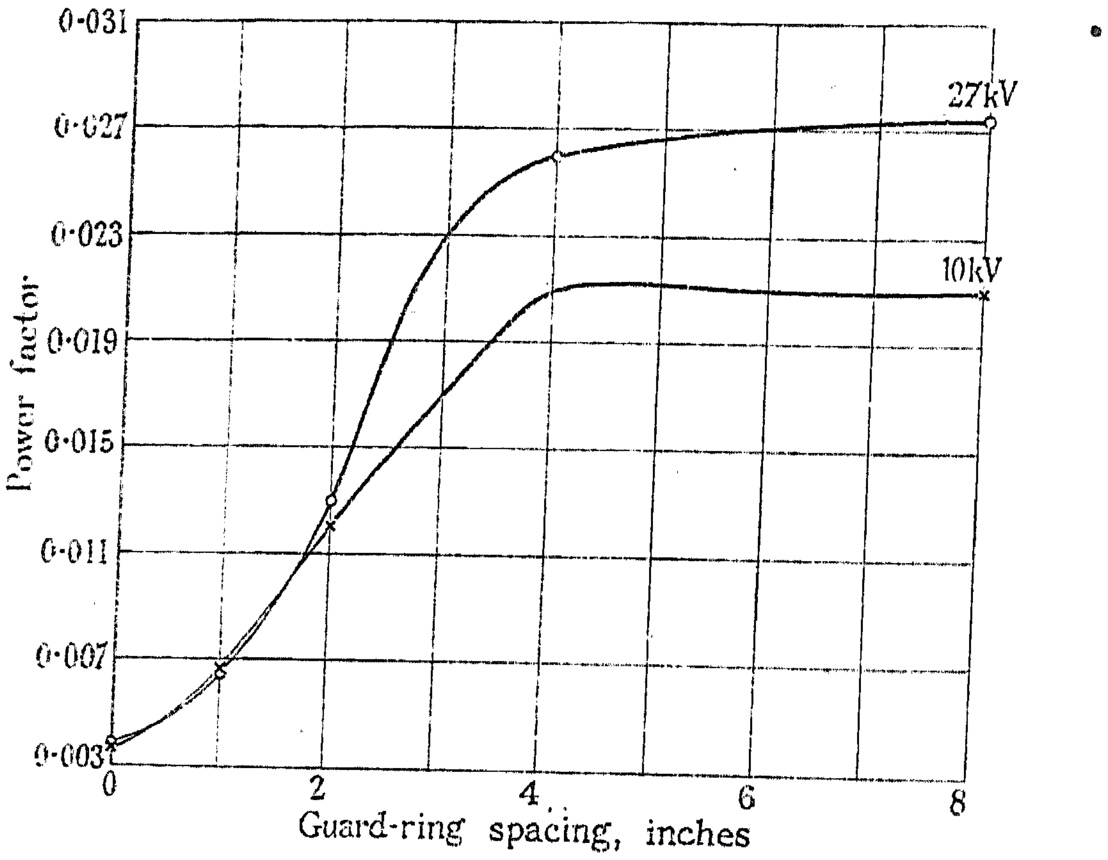

FIG. 6.—Variation of power factor with guard-ring spacing. 3 ft. of 66-kV single-core cable with 1-in. wide guard rings and 3-ft. ends, after 24 hours.

The power factor/voltage characteristics of cables are, however, often required up to at least twice the working voltage, and in order to complete the experimental data it was considered necessary to carry the voltage up to at least 80 kV. The object of the test was to determine whether any fresh phenomena were encountered at the higher voltages.

The extension of the voltage range necessitated the use of some special device to prevent flash-over. Copper cone spinnings slipped over the core and filled with petroleum jelly, as shown in Fig. 7, were found most convenient.

The portions of the core AB were stripped of metallized paper and the guard separation was adjusted by winding lead-foil strip downwards from B to C until the required gap CA was obtained. As the gap CA was never made greater than 2 inches, the length of guard was never less than 9 inches plus the length of the end cone.

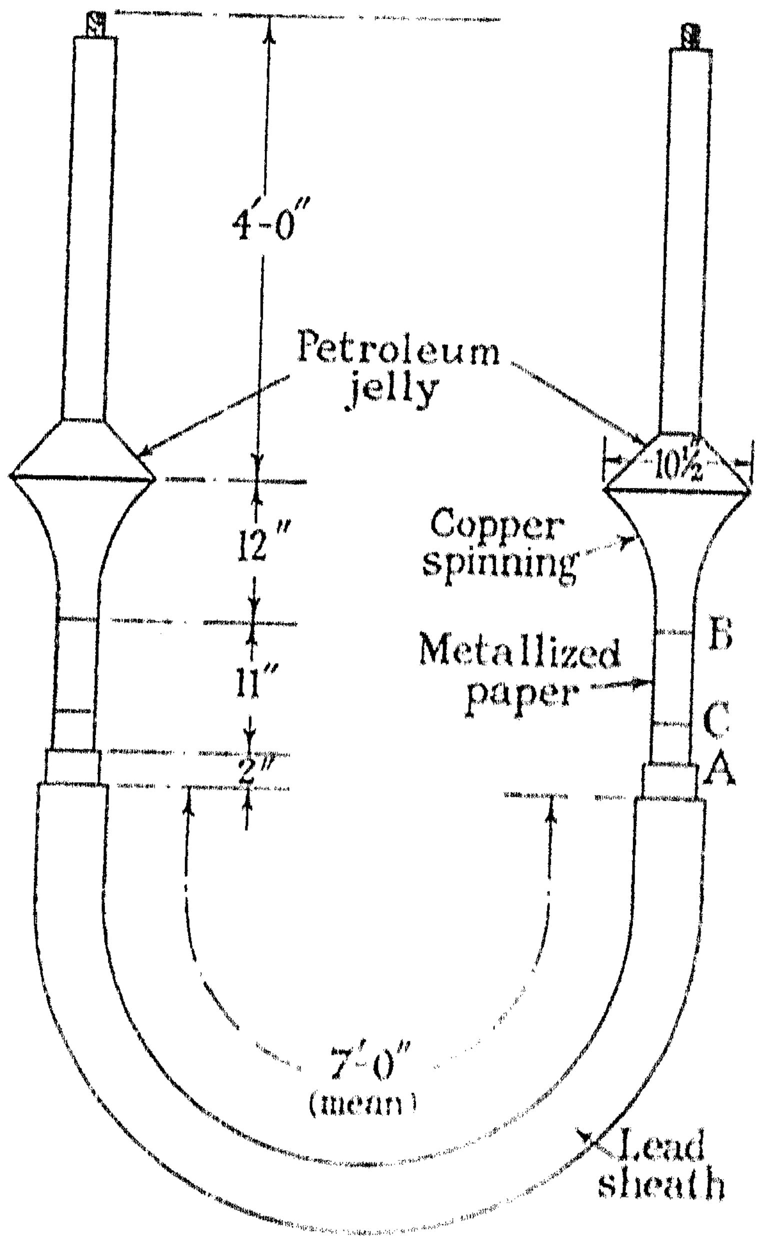

FIG. 7.

The cables available for the tests were rated at 66 kV (3-phase) and were similar in design to the sample tested above, but were cut from a length which had undergone a prolonged life test on overload at excess voltage. The sheath of the cable could be completely screened at will by an envelope of metallized paper connected to the

TABLE 6.

Power-Factor Tests on 66-kV Cable Provided With End Cones.

Separation between guard and sheath	Screening	Freshly opened core				Open 4 hours or more				
		Power factor (per cent) at				Time open	Power factor (per cent) at			
		20 kV	40 kV	60 kV	80 kV		20 kV	40 kV	60 kV	80 kV
inches						hours				
$\frac{1}{16}$	Unscreened ..	0·51	0·52	0·545	0·56	40	0·49	0·555	0·58	0·585
	Screened	0·505	0·515	0·525	0·53	40	0·51	0·55	0·58	0·56
$\frac{1}{2}$	Unscreened ..	0·51	0·545	0·57	0·58	40	0·52	0·57	0·59	0·595
	Screened	0·525	0·54	0·55	0·56	40	0·54	0·59	0·61	0·61
2	Unscreened ..	—	—	—	—	4	0·625	0·80	0·86*	0·83*
						18	0·73	0·86	0·88	0·87
	Screened	—	—	—	—	4	0·67	0·85	0·83	0·82
11	Screened	0·53	0·665	0·745	0·785	—	—	—	—	—

* Unsteady.

guard. Tests were carried out immediately after the removal of the metallized paper from AB and after various periods, as shown in Table 6.

Owing to the previous overstraining of the dielectric accurate re-check tests were not always obtained, and the applied voltage was not carried above 80 kV. It will, however, be noted from the table that the character of the results is very similar to that observed at lower voltages, although there appears to be a tendency for the power factor of a screened cable at low voltages to be slightly higher than that of an unscreened cable. The effect has been mentioned by other observers, but as the variation is very small, particularly with the most efficient guard system ($\frac{1}{16}$ in. separation), the phenomenon has not been examined further.

(3) Theoretical Discussion of the End Loss.

The results of the above experiments indicate clearly that the loss occurs on or over the surface of the core in the vicinity of the earthed electrode. This loss may take place:—

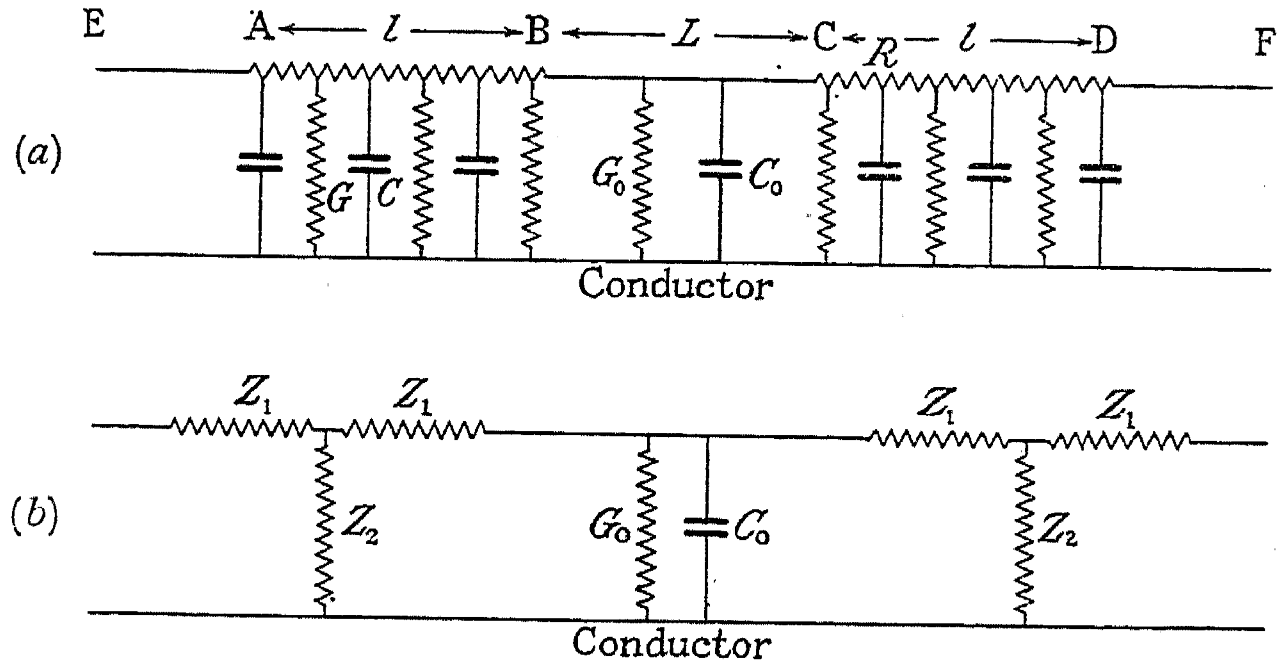

FIG. 8.

(a) on the surface of the core, due to a film of condensed moisture, dirt, etc.;
(b) along the surface of the core, due to sparks which extend outwards from the earthed electrode at higher voltages; or
(c) in the neighbouring air, due to high-conductivity glow discharge or corona.

In the subsequent text the term "resistance" will signify, therefore, the apparent resultant resistance of all these parallel paths from a particular point on the core to the sheath or guard ring.

Since (a) and (b) above are not amenable to direct mathematical treatment, we shall confine ourselves first to a core having a uniform surface resistance of definite and constant ohmic value. Such a case might be approximated to in practice by a hygroscopic core at high or normal relative humidity, or a cable immersed in brine which has crept up the core forming a high-resistance film extending a definite distance above the brine level.

E. W. Smith[*] in a recent paper has indicated briefly that, in the latter case, a definite increase in loss occurs at the ends and that this has a maximum value for a particular value of surface resistance. Considering this case first, Fig. 8(a) shows diagrammatically a cable of length L immersed in brine BC; AB and CD represent high-resistance films of length l on the surface of the core, and EA and DF are the remainders of the ends with an assumed infinite surface resistance.

It is required to determine the resultant power factor between the conductor and brine on a cable having the following constants:—

G_0 and C_0 = total leakance and capacitance respectively within the brine;
R = resistance per unit length of the surface film;
G and C = leakance and capacitance respectively of the dielectric per unit length of core.

There is in addition a certain capacitance effect along the film surface, but as it will be assumed that the surface capacitance is small compared with the surface conductance, the former will be neglected.

The problem is thus analogous to that met with in telephonic transmission over a line with uniformly-distributed leakance and capacitance and an open receiving end. The system may be replaced by the equivalent T network shown in Fig. 8(b),[*] in which

$$Z_1 = Z_0 \tanh \tfrac{1}{2}\theta \quad . \quad . \quad . \quad . \quad . \qquad \text{(i)}$$

$$Z_2 = Z_0/\sinh \theta \quad . \quad . \quad . \quad . \quad . \qquad \text{(ii)}$$

Now

$$Z_0 = \sqrt{[R/(G + j\omega C)]}, \quad \text{and} \quad \theta = l\sqrt{[R(G + j\omega C)]}.$$

Since G is small compared with ωC, it can be neglected in the following simplification.

Thus $\quad Z_0 = \sqrt{[R/j\omega C]}, \quad$ and $\quad \theta = l\sqrt{(j\omega CR)}$

Therefore

Total admittance from core to sheath

$$= \frac{1}{Z} = G_0 + j\omega C_0 + \frac{2}{(Z_1 + Z_2)}$$

Substituting the values of Z_1 and Z_2 from (i) and (ii) and simplifying,

$$\frac{1}{Z} = G_0 + j\omega C_0 + \frac{2}{Z_0}\tanh \theta$$

Now

$$Z_0 = \sqrt{\left(\frac{R}{j\omega C}\right)} = (1 - j)\sqrt{\left(\frac{R}{2\omega C}\right)} = (1 - j)\frac{\sigma}{\omega C}$$

and $\quad \theta = l\sqrt{(j\omega CR)} = l(1 + j)\sqrt{(\tfrac{1}{2}\omega CR)} = l(1 + j)\sigma$

where $\qquad \sigma = \sqrt{(\tfrac{1}{2}\omega CR)}$

Therefore

$$\frac{1}{Z} = G_0 + j\omega C_0 + \frac{2\omega C}{(1 - j)\sigma}\tanh l(1 + j)\sigma$$

$$= G_0 + j\omega C_0 + \frac{\omega C(1 + j)}{\sigma}\left(\frac{\tanh l\sigma + j\tan l\sigma}{1 + j\tanh l\sigma \tan l\sigma}\right)$$

Simplifying and collecting,

$$\frac{1}{Z} = \left[G_0 + \frac{\omega C}{\sigma}\left(\frac{\sinh 2l\sigma - \sin 2l\sigma}{\cosh 2l\sigma + \cos 2l\sigma}\right)\right] + j\left[\omega C_0 + \frac{\omega C}{\sigma}\left(\frac{\sinh 2l\sigma + \sin 2l\sigma}{\cosh 2l\sigma + \cos 2l\sigma}\right)\right]$$

---

[*] "Alternating-Current Tests on High-Speed Telegraph Cables," *Journal I.E.E.*, 1930, vol. 68, p. 453.

[*] See J. G. HILL: "Telephonic Transmission," p. 361.

*

Therefore

$$\text{Total power factor} = \frac{G}{\omega C} = \frac{\dfrac{G_0}{\omega C_0} + \dfrac{C}{C_0\sigma}\left(\dfrac{\sinh 2l\sigma - \sin 2l\sigma}{\cosh 2l\sigma + \cos 2l\sigma}\right)}{1 + \dfrac{C}{C_0\sigma}\left(\dfrac{\sinh 2l\sigma + \sin 2l\sigma}{\cosh 2l\sigma + \cos 2l\sigma}\right)}$$

An analysis of the denominator shows that under practical conditions the second term can be neglected, since the value of

$$\frac{\sinh 2l\sigma + \sin 2l\sigma}{\cosh 2l\sigma + \cos 2l\sigma}$$

is never greater than 1·4, and the value of $(C/C_0\sigma)$ is never greater than 0·1 for the cases which arise in normal cable practice.*

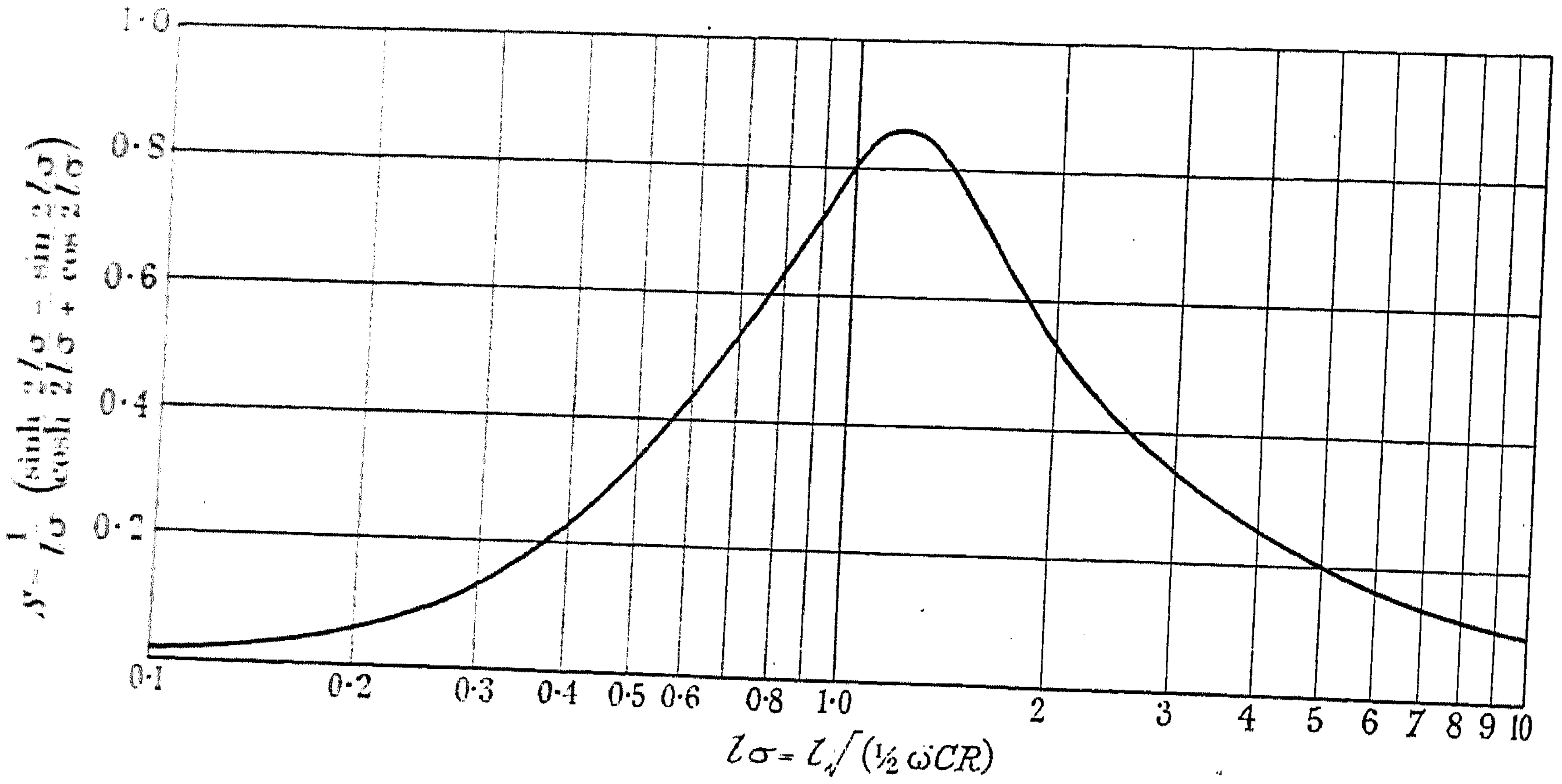

FIG. 9.—Cable and losses.

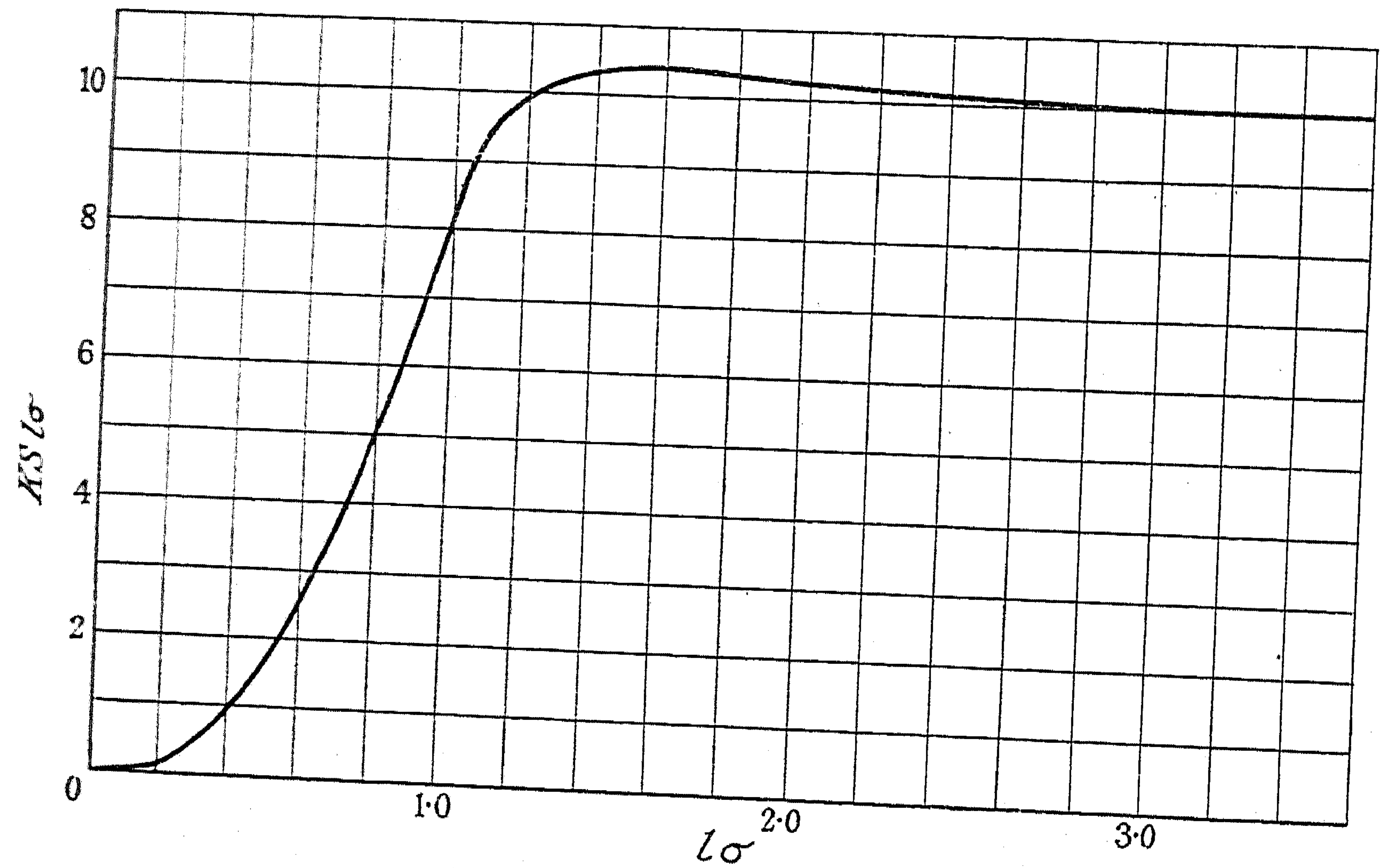

FIG. 10.—Cable and losses.

Then

$$\text{Power factor} = \frac{G_0}{\omega C_0} + \frac{C}{C_0\sigma}\left(\frac{\sinh 2l\sigma - \sin 2l\sigma}{\cosh 2l\sigma + \cos 2l\sigma}\right) \quad . \quad \text{(iii)}$$

Now $C_0 = CL$, where L = length of sheathed cable.

Equation (iii) can therefore be rewritten in the form:—

$$\text{Power factor} = \frac{G_0}{\omega C_0} + \frac{l}{L}\cdot S \quad . \quad . \quad . \quad \text{(iv)}$$

where $$S = \frac{1}{l\sigma}\left(\frac{\sinh 2l\sigma - \sin 2l\sigma}{\cosh 2l\sigma + \cos 2l\sigma}\right)$$

The first term of expression (iv) is the normal power factor of the dielectric, and the second term gives the incremental power factor due to end loss.

Fig. 9 shows the calculation of S for values of $l\sigma$ up to 10; for higher values, $S = 1/l\sigma$. From this curve we can obtain another one showing how the power factor rises with increase in the length of film, the values of R and C remaining constant. Multiplying the ordinates of Fig. 9 by a constant times the corresponding abscissæ, we obtain Fig. 10.

Now, for small values of $l\sigma$,

$$S = K_1 l^2$$

For $$\sinh 2l\sigma - \sin 2l\sigma = K_2 l^2$$

and $$\cosh 2l\sigma + \cos 2l\sigma = 2 = \text{constant}$$

---

* Where very unusual conditions obtain, the whole denominator must be evaluated.

Therefore $\quad$ Power factor $= K_3 l^3$

This relationship holds fairly well up to $l\sigma = 0{\cdot}8$.

For values of $l\sigma$ greater than about 3,

$$S = K_4/l$$

whence the power factor is a constant. Actually, the power factor is practically constant for values of $l\sigma$ greater than 1·2.

It is evident, therefore, that initially the power factor increases as the cube of the film length, but finally becomes constant for all values of $l\sigma$ greater than 1·2.

This curve is in very good agreement with the type of experimental curves shown in Figs. 2 and 3 on low-voltage, and in Fig. 6 on high-voltage cores with different guard-ring spacing.

(4) Calculations from Theoretical Formula.

The curve of Fig. 9 forms the basis for a set of calculations to show the value and variation of the theoretical loss which can occur in two typical cables under different conditions of surface resistance, frequency, etc. It is assumed that the dielectric is perfect in each case (i.e. $G_0/\omega C_0 = 0$), and only the incremental power factor due to the end loss is considered. The particulars of the two cable types are:—

A. 10 ft. of standard gutta-percha telegraph cable.
Conductor diameter = 0·185 in.
Diameter over dielectric = 0·445 in.
Specific inductive capacity of gutta-percha = 3·2

B. 10 ft. of 0·2-sq. in. impregnated-paper 66-kV single-core cable, similar to that on which the experimental tests were carried out.

These two cables were found to have almost exactly the same value for C (capacitance per unit length), so that the same calculation applies equally to both.

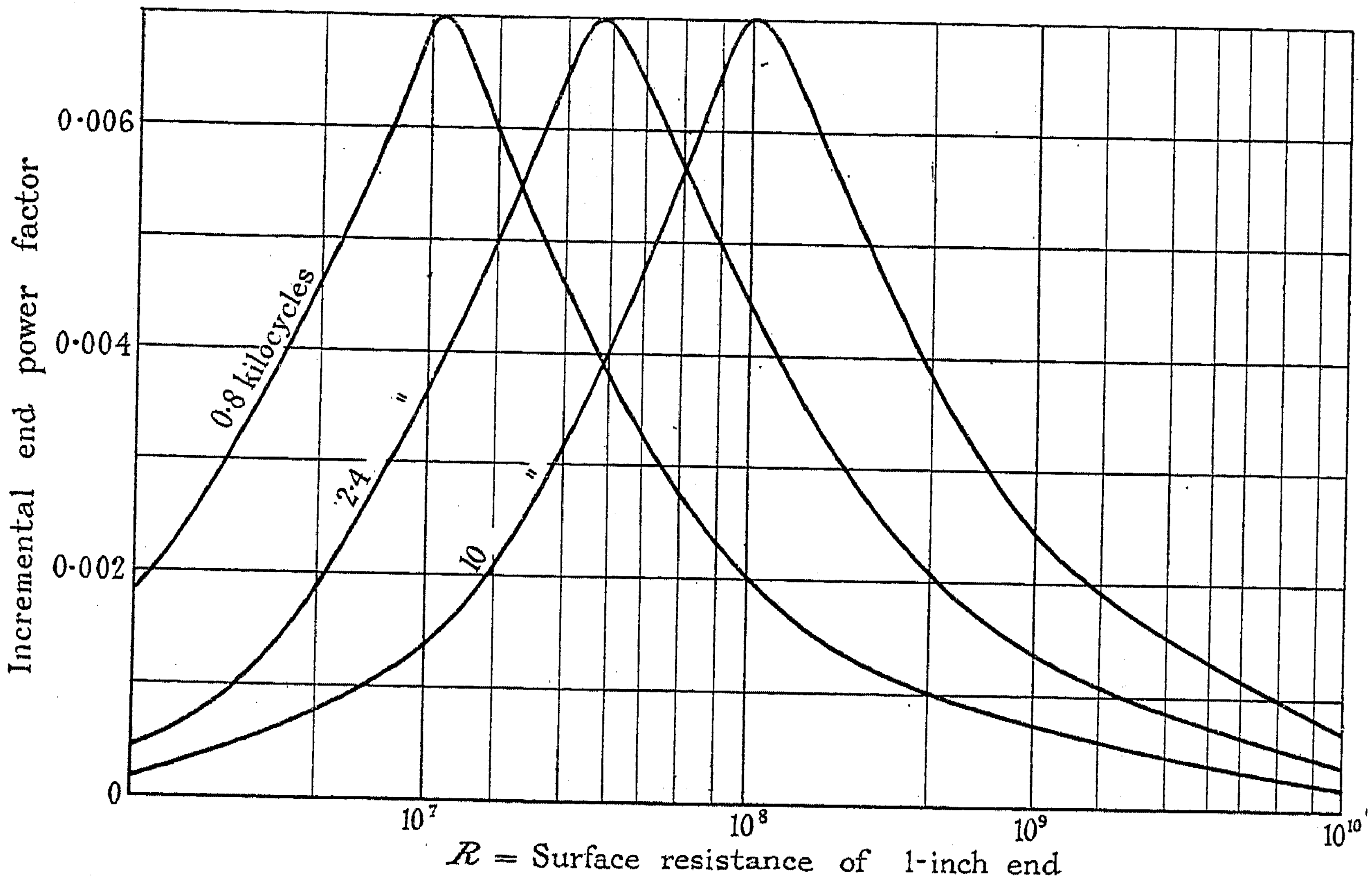

Fig. 11.—Variation of end power factor with frequency, on a 1-in. end of surface resistance R.

Table 7 shows a series of calculations for different conditions. Columns (*b*), (*c*), and (*d*), are particularly applicable to cable A, where for 1 in. above the brine surface the core might have a relatively low surface resistance. The power factors for the three frequencies are plotted in Fig. 11. Columns (*e*), (*f*), and (*g*), give the 800-cycle power factors for 2-, 6-, and 12-in. cable ends which might be subjected to high humidity. The figures for the low resistances have not been calculated, as the formulæ derived above only apply accurately to an open-circuited receiving end [as in columns (*b*), (*c*), and (*d*)] or to a line for which θ is greater than about 2, in which case the short-circuited line values agree very closely with those for the open condition. Results for such low resistances were not deemed necessary, but if required a formula can readily be obtained from the T network shown in Fig. 8(*b*). In this case, of course, the power factor will not be independent of the length of end. In the limit, with R very small, the end-loss proper—as indicated in this paper—disappears, and only a direct leakance over the end exists, the " power factor " varying inversely as the length of end. For values of the surface resistance greater than 10^7 to 10^8 ohms per inch length, the power factor due to the ends is shown to be independent of the length of end when this exceeds 3 to 4 in. Columns (*h*) and (*j*) give a similar indication for cable B under a 50-cycle test.

Table 8 has been drawn up to show the variation with different values of surface resistance of:—

(i) The length of end required to give maximum end-loss. Lengths in excess of these values produce no additional loss.
(ii) The maximum end-loss power factor which can be obtained and would be given by any length of end equal to or greater than that given in (i).

The small power factors calculated for the higher surface resistances (10^{10} to 10^{11} ohms per inch) may be somewhat in error due to the fact that the capacitances along the surface to the core, which do not lend themselves to mathematical treatment, are commensurable with the surface resistance.

The plotting of columns (*b*), (*c*), and (*d*) in Fig. 11 is of particular interest, and shows that very great care is necessary in the preparation of the ends of relatively short submarine-cable samples. The great variation of power factor with frequency may account to some extent for the curious unstable power factor/frequency characteristics sometimes obtained on short samples.

TABLE 7.

Theoretical End Power Factors of Cable Samples A *and* B.

Surface resistance R, in ohms per inch length	Power factor due to 1 in. of end* with surface resistance R			Power factor due to an end with surface resistance R				
				2-in. end	6-in. end	12-in. end	12-in. end	36-in. end
	800 cycles per sec.	2 400 cycles per sec.	10 000 cycles per sec.	800 cycles per sec.	800 cycles per sec.	800 cycles per sec.	50 cycles per sec.	50 cycles per sec.
(*a*)	(*b*)	(*c*)	(*d*)	(*e*)	(*f*)	(*g*)	(*h*)	(*j*)
10^6	0·0001	0·0005	0·0018	—	—	—	—	—
10^7	0·0015	0·0039	0·0068	—	0·024	0·023	0·083	0·093
10^8	0·0069	0·0044	0·0020	0·0075	0·0075	0·0073	0·028	0·029
10^9	0·0023	0·0013	0·0007	0·0023	0·0023	0·0023	0·0094	0·0094
10^{10}	0·0007	0·0004	0·0002	0·0008	0·0008	0·0008	0·0029	0·0029
10^{11}	0·0002	0·0001	0·0001	0·0002	0·0002	0·0002	0·0009	0·0009

* Total length of end greater than 1 in.

TABLE 8.

Characteristics of End Loss on Cables A *and* B.

Surface resistance R	Length of end required to give maximum end loss		Maximum end-loss power factor	
	800 cycles per sec.	50 cycles per sec.	800 cycles per sec.	50 cycles per sec.
ohms per inch length	inches	inches		
10^6	10	—	0·071	—
10^7	3·2	12·6	0·023	0·089
10^8	1·0	4·0	0·0071	0·028
10^9	0·3	1·3	0·0023	0·0089
10^{10}	0·1	0·4	0·0007	0·0028
10^{11}	—	0·13	—	0·0009

(5) DISCUSSION OF EXPERIMENTAL RESULTS.

The series of tests taken on low-voltage cable with various wire spacings, etc., are readily explained by the end-loss theory developed above.

In the preliminary stages of the investigation it was thought possible that the end loss might occur within the dielectric at the ends. At the termination of the sheath the stress lines do not pass radially through the dielectric, but have a large longitudinal component which will act along the paper layers. As impregnated paper is weaker electrically in this direction, the source of loss might originate in the interfaces between paper layers. Later experiments showed, however, that this loss, if present, is inappreciable.

During the course of the experimental work it was shown that the power factor varied with voltage. This is readily explained in the case of moderate and high voltages by surface sparking, corona, etc., but the effect was also noticed at voltages of 5 000 volts and less. The only apparent explanation of this behaviour seems to be due to the fact that the moisture condenses in the oil surfaces in very minute drops. Under the action of electric stress these globules elongate in the direction of

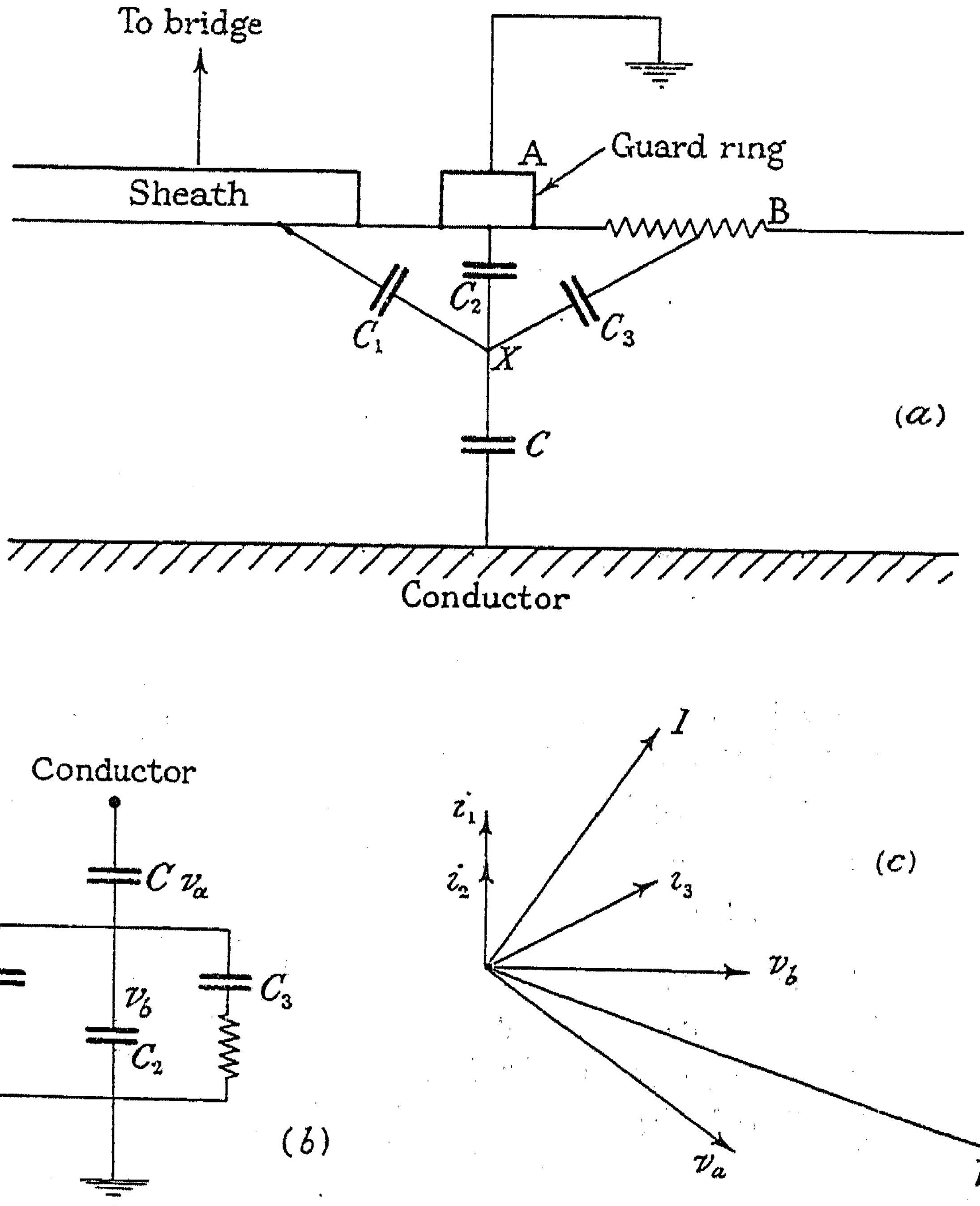

FIG. 12.

the field and reduce the surface resistance, causing an increase in power factor.

It might be expected that the heat produced in the end loss would cause the moisture film to evaporate and that, after a short time, the power factor would drop. No such drop, however, has been particularly noticed, but the effect has not been sought after. A calculation shows that the normal end loss is probably of the order of 1 watt per inch for 1 or 2 inches, so that this relatively small effect may be annulled by the usual tendency of the power factor of a cable to rise slightly during the first hour or so under voltage.

The use of a high-resistance film such as photographic carbon paper has been demonstrated for increasing the flash-over voltage on a core.* The heat dissipation in this resistance is usually very high, and it is impossible to measure accurately the power factor on a cable equipped direct with this type of end. By fitting the resistance ends to the guard ring the loss is eliminated from the test circuit.

The noticeable fall in power factor with short guards at higher voltages is contrary to expectation, and requires an explanation. The following solution appears to be highly probable. Consider the end section of a cable fitted with a short guard, as shown in Fig. 12(*a*). The surface A B has a surface resistance due to humidity, sparking, etc. Then the potential of the point X in the dielectric is fixed by the capacitance-resistance combination shown. This is simplified in Fig. 12(*a*), and the corresponding vector diagram is given in Fig. 12(*c*). It is evident that the current in C_1 leads the cable voltage by an angle considerably greater than 90° C. The injection of a current of this phase into the bridge circuit cancels out a certain amount of the " lagging " leakage current, resulting in a fall of cable power factor.

The use of a long guard-ring, resulting in a radial field near the end of the sheath, will eliminate this error. In normal capacitance measurements with a guard ring it is usual to make the width of the guard ring 6 to 8 times the dielectric thickness, in order to ensure an almost radial field at the end of the test electrode. It is advisable then to use a similar rule for the length of guard ring on h.t. cables.

The fact that agreement to within about 0·0002 in the power-factor values is obtained under these conditions on 2- and 3-ft. samples is sufficient indication of the accuracy which would be obtained on greater lengths.

Experiments on submarine-cable cores immersed in brine to check the variation of end loss under different conditions have not been successful for various reasons, chiefly the difficulty in maintaining a film of definite length and known resistivity constant during a set of tests. A maximum point (as shown in Fig. 11) was observable, but no values were obtained.

(6) RECOMMENDATIONS FOR PRACTICAL END-GUARDING.

Submarine Cable.

The best method of eliminating the trouble suggested by this study is to extend artificially the conducting sheath represented by the brine above the surface in one of the following ways: (*a*) wide-angle tin cones filled with a low melting-point wax which adheres rigidly to the surface of the core dielectric [Fig. 13(*a*)]; (*b*) metal-sprayed end sections [Fig. 13(*b*)]; (*c*) a relatively low-conductivity material applied to the core; e.g. a polished coat of powdered graphite, which has a surface resistance of about 2 000 ohms per sq. in., a value sufficiently low to produce no appreciable loss over the audio-frequency range. A top dressing of rubber solution or similar material applied over the end of the covering prevents the graphite from smearing up the core and forming a high-resistance film [Fig. 13(*c*)]. The use of " Aquadag " with no surface dressing has been found to be very satisfactory in practice.

As these methods also define clearly the length of core under test, it is possible to take comparative capacitance tests on shorter lengths.

In order to be effective the methods described above assume that at the end of the artificially extended sheath there is a sudden transition from a low resistance to an infinite resistance. At relatively high humidities or on a highly hygroscopic surface there may therefore exist in addition a very appreciable loss at the termination of the artificial sheath. Fig. 13(*a*) should be least susceptible to this trouble, as at the end of the core the capacitance to core is extremely small. In the other cases the best preventative is to ensure that the surrounding air has a relatively low humidity.

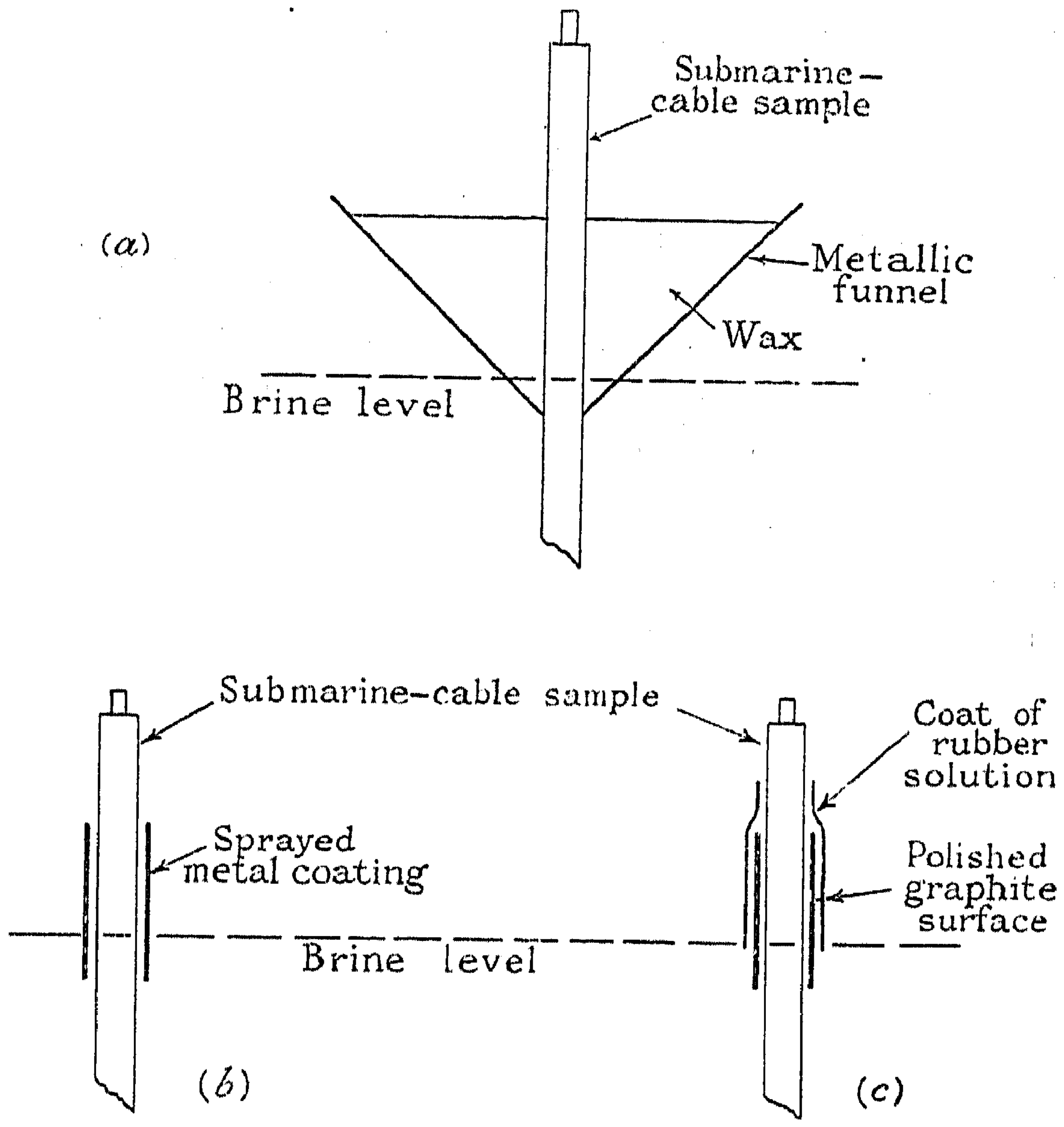

FIG. 13.

Power Cable.

For ordinary testing on the low-voltage side a guard ring consisting of a tightly-lapped metallic sheath in length about 8 times the dielectric thickness, fixed close to the end of the cable sheath, has proved quite satisfactory on even the shortest lengths. A good method is to make a circumferential cut through the lead sheath and metallized paper (if present) about 6 inches from the end of the lead sheath, and to slide the lead tube up the core sufficiently to insert a $\frac{1}{8}$-in. split insulating washer. The lead tube is then forced back against the washer and an ordinary end funnel filled with compound is attached to the guard so formed. The combination gives a good flash-over voltage coupled with an efficient guard. For cable lengths exceeding 100 yards it has not usually been considered necessary to apply guards, but it is now found advisable to attach guards to every length of cable where possible.

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* British Patent No. 290401.

A guard ring, in addition to eliminating a source of error from the measurements, acts as a safety device for the bridge circuit in case of flash-over. At lower voltages it eliminates the minor sparking at the lead sheath which frequently prevents a bridge balance.

A particular drum length of cable was pressure-tested at 180 kV for 15 minutes with the ends unguarded, submerged in oil tanks, and was followed by a power factor/voltage run which yielded a very erratic rising power factor. The ends were examined and signs of " tracking " were observed on the outer paper near the sheath. Guard rings were fitted and a steady and much lower power factor curve resulted.

The testing of cables on the h.t. side is rarely required nowadays on sample and drum lengths of cable. On buried cables the necessity occasionally arises, but the length of cable is usually sufficient to render possible the omission of a guard. The development of a successful guard for the h.t. side, however, presents considerable difficulty if the flash-over voltage or breakdown strength of the end is not to be impaired. The use of end funnels well filled with good compound will usually reduce the end loss to a very low figure.

(7) CONCLUSIONS.

(*a*) The losses occurring at cable ends are not primarily due to the effect of high voltage (ionization or corona), as similar results are obtained at 40 volts.

(*b*) The mechanism of the loss is due to a high surface resistance along the core shunted by a uniformly distributed capacitance to the conductor.

(*c*) The theoretical treatment of this system is shown to agree well with experimental results, and indicates that high surface resistances which would produce no appreciable loss due to direct leakage over the ends may give rise to considerable loss when considered in conjunction with the core capacitance.

(*d*) The loss, which occurs in both submarine- and power-cable samples, depends on the effective surface resistance—a very unstable variable.

(*e*) The loss is shown to increase initially as the cube of the distance of the film from the sheath, normally reaching a constant value after 1 or 2 in. Thus, for usual power-cable ends, the loss is independent of the length of end.

(*f*) The end loss can be eliminated from power-cable testing by the use of a guard consisting of a tightly-lapped metallic sheath fixed close to the end of the cable sheath and in length about 8 times the dielectric thickness.

(*g*) Suitable methods are available for minimizing the end loss on submarine-cable samples immersed in brine.

The author's thanks are due to the International Telephone and Telegraph Laboratories Incorporated, Hendon, for permission to publish this work.

PROCEEDINGS OF THE INSTITUTION.

820TH ORDINARY MEETING, 5TH NOVEMBER, 1931.

Mr. J. M. Donaldson, M.C., President, took the chair at 6 p.m.

The Minutes of the Ordinary Meeting held on the 22nd October, 1931, were taken as read and were confirmed and signed.

Messrs. G. M. Maddock and R. Tervet were appointed scrutineers of the ballot for the election and transfer of members, and, at the end of the meeting, the President reported that the members whose names appeared on the lists (see page 102) had been duly elected and transferred.

The President announced that, during the month of October, 42 donations and subscriptions to the Benevolent Fund had been received, amounting to £18.

He also drew attention to the portrait of the late Dr. S. Z. de Ferranti, by Mr. D. Jagger, which had been presented to the Institution by Mr. H. Marryat and had been hung in the Lecture Theatre, and he asked the donor to say a few words about the portrait and its subject.

Mr. H. Marryat: I am very happy to be instrumental in providing the Institution with this portrait of the late Dr. de Ferranti, and I am sure we are all glad to have it hanging in our theatre, where we have so often been inspired by his addresses. Ferranti had an extraordinary power of attraction and inspiration. His charming personality, ready wit, and brilliant imagination, and his obvious sincerity and modesty, made a combination which was irresistible. In addition, he had a wonderful faculty for clear thinking, which often enabled him to see farther ahead than most of us. An outstanding example of this was the pioneer work which he carried out at Deptford when he was only about 25 years of age. In those days I was one of a group of apprentices who made a hero of Ferranti. I remember pilgrimages to see the progress of the works and to watch those wonderful cables being laid; I think those visits gave some of us ideas of doing something big ourselves one day. However that may be, I do believe that we each one of us did better for the example of pluck and perseverance in the face of difficulties which Ferranti set before us. One of the last things in which he was interested was an endeavour to standardize the charge for domestic electricity throughout the country. He believed that a fixed flat-rate of, say, ½d. or 1d. per unit, plus a standing charge varying with the locality, would do more than anything else to develop the use of electricity. The work of the committee which he formed to consider this proposition was interrupted by his death; but Ferranti was so often right in matters of this sort that I think the proposal is one which might well be reconsidered. We are to be congratulated upon securing the services of Mr. David Jagger as our artist. No one could possibly have taken more trouble, and the task was one of peculiar difficulty because of the meagreness of the available material. It is typical of Ferranti's modesty that there should be no painting of him, and only one studio portrait. We are much indebted to friends who kindly lent snapshots, but here again Ferranti's modesty was our undoing, for he never took a prominent position in a group. Despite these difficulties, it is gratifying to know that Mrs. de Ferranti and members of the family consider the portrait to be a good one.

The President: On behalf of the Institution I accept with many thanks Mr. Marryat's munificent gift. To what Mr. Marryat said about Ferranti I can add nothing except this: that all of us who knew him loved him, and all those who did not know him admired him. We shall never forget Ferranti's name, nor shall we now forget his face. I think it is unnecessary for me to move a formal vote of thanks, and I shall let your applause stand as a token of your feelings.

A paper by Mr. E. A. Watson, O.B.E., Associate Member, entitled "Coil Ignition Systems" (see page 105), was read and discussed.

The meeting terminated at 7.35 p.m. with a vote of thanks to the author, which was moved by the President and carried with acclamation.

821ST ORDINARY MEETING, 19TH NOVEMBER, 1931.

Mr. J. M. Donaldson, M.C., President, took the chair at 6 p.m.

The minutes of the Ordinary Meeting held on the 5th November, 1931, were taken as read and were confirmed and signed.

A list of candidates for election and transfer, approved by the Council for ballot, was taken as read and was ordered to be suspended in the Hall.

A paper by Messrs. E. W. Dickinson, Member, and H. W. Grimmitt, Associate, entitled "The Design of a Distribution System in a Rural Area" (see page 189), was read and partly discussed. On the motion of the President, a vote of thanks was accorded to the authors for their paper, the further discussion of which was adjourned until the 26th November, 1931.

The meeting terminated at 7.45 p.m.

INSTITUTION NOTES.

Summer Meeting, 1932.

The Council have accepted an invitation from the North Midland Centre for the Summer Meeting this year to be held in Yorkshire (Harrogate, Leeds, and Sheffield) from the 31st May to the 3rd June. A preliminary circular regarding the Meeting will shortly be issued to members.

Faraday Medal.

At the Ordinary Meeting of the Institution held on the 21st January the President announced that the Council had that day made the eleventh award of the Faraday Medal to Sir Oliver Lodge, D.Sc., F.R.S., an Honorary Member of the Institution.

Honorary Member.

At the same meeting the President also mentioned that the Council had elected Mr. W. M. Mordey, Past President, an Honorary Member of the Institution.

George Montefiore Prize, 1932.

The Secretary of the Institution has been requested to remind members that the last date for the receipt of papers in connection with the above award (see *Journal I.E.E.*, 1931, vol. 69, page 554) is the 30th April.

Faraday Centenary Celebrations.

The Council of the Institution have passed the following Resolution of Thanks in connection with the above Celebrations:—

> "The Council desire to record their satisfaction and appreciation of the part taken by Col. Vignoles, as the originator and responsible organizer of the Faraday Centenary Exhibition, for the unsparing way in which he put his talents at the service of the Exhibition and inspired others to do the same.
>
> "They wish to acknowledge the indebtedness which they consider the electrical industry owes to the Council and staff of the British Electrical Development Association in putting their organization so entirely at the disposal of Col. Vignoles for the purposes of the Exhibition.
>
> "And they desire to thank and to congratulate most warmly all the organizations and individuals who were responsible for the different exhibits and demonstrations at the Exhibition."

Opening of Sydney Harbour Bridge.

The Institution of Engineers, Australia, have sent a cordial invitation to any member of the Institution of Electrical Engineers who may be visiting Australia at the time of the opening of the Sydney Harbour Bridge in March 1932, to forward their names and addresses to the Secretary of the former Institution, in order that they may be given an opportunity of taking part in the celebrations which will be organized by the Australian Institution on that occasion. Communications should be addressed to the Secretary, The Institution of Engineers, Australia, Science House, Gloucester and Essex Streets, Sydney, New South Wales.

Graduateship Examination Results: November, 1931.

*Passed.**

Ashton, H. F. (Newcastle-on-Tyne).
Bailey, H. G. (Woking).
Boag, D. J. W. (Glasgow).
Boyd, J. S. (Edinburgh).
Brown, W. E. (Gateshead).
Burch, J. T. (Leigh-on-Sea).
Callaghan, R. J. (London).
Cliff, J. S. (Birmingham).
Duckworth, A. W. S. (Carlisle).
Dunkley, R. A. (Bexhill-on-Sea).
Fareham, J. (Doncaster).
Fuad, I. (London).
Gowdridge, F. (Kirby Muxloe).
Graham, A. O. (Bolton).
Green, C. (Edgware).
Hancox, L. J. (Blackpool).
Hayter, D. E. (W. Hagley).
Holmes, V. I. (Bearsden).
Horsington, L. R. (Lee-on-Solent).
Jackson, J. B. (Newcastle-on-Tyne).
Larkin, A. S. (Southampton).
Lugg, J. V. (Gloucester).
McIlvride, K. J. A. (London).
Markwick, A. H. D. (Brighton).
Morris, M. (Rhondda).
O'Dell, E. R. (Stourport).
Partington, H. L. (Over Hulton).
Pringle, R. W. (Rugby).
Probert, G. A. (Gloucester).
Rowe, A. H. R. (Devonport).
Stewart, D. (Glasgow).
Stirrat, J. (Glasgow).
Sutton, E. J. (London).
Thorn, J. G. (Dovercourt).
Topham, H. B. (Wallsend).
Turner, J. H. (Bowdon).
Vodden, C. E. (Leamington Spa).
Waddon, E. A. (Burton-on-Trent).
Waine, I. L. (Tamworth).
Wakefield, K. S. (London).
Westaway, G. A. (Barnstaple).
Wijetilaka, B. (Berlin).
Zaki, S. (London).

Passed Part I only.

Mann, W. V. W. (London).
Parsons, D. R. (Lichfield).
Pattinson, R. R. (Newcastle-on-Tyne).
Pyman, E. J. R. (Lowestoft).
Ridge, G. R. C. (Taunton).
Thomas, A. R. (Rhondda).
Watts, H. E. G. (Shepperton-on-Thames).

Passed Part II only.

Blakeley A. R. (London).
Chisholm, R. Y. (Neilston).
Duff, D. (Birmingham).
Goodall, W. E. (Nuneaton).
Hansford, R. G. C. (Shanklin).
Holder, A. J. M. (Newcastle-on-Tyne).
Howard, F. W. M. (London).
Hudson, H. F. (Worcester).
Kennan, L. W. (Dublin).
Kennion, W. R. (Hove).
Kyffin, J. J. N. (Hornchurch).
Neave, J. W. C. (Aylesbury).
Percival, W. S. (Swanley).
Setterfield, E. J. (Kingsbury).
Winskill, J. E. (Middlesbrough).

Further results relating to candidates who sat for the Examination abroad will be published later.

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* This list also includes candidates who are exempt from, or who have previously passed, a part of the Examination and have now passed in the remaining subjects.

Telephones in New Buildings.

The Postmaster-General will gladly supply to any member to whom it may be of service a copy of a recent official publication entitled "Facilities for Telephones in New Buildings." The booklet is designed with the primary aim of ensuring co-operation between architects, building contractors, surveyors, technical engineers and the Post Office engineers, to the advantage of all concerned. Application for copies should be made direct to the General Post Office, London, E.C.1.

Membership Transfers.

The following transfers have been effected by the Council:—

Associate to Graduate.

Rudd, Donald, B.Sc.

Student to Graduate.

Adney, William Stanley.
Andrews, Frederick Oswald, B.Sc.(Eng.).
Astbury, Herbert Purcell.
Bailey, John William.
Beaton, Robert Frederick.
Bellis, Francis Joseph.
Bennetts, Humphrey Graham.
Berkeley, Bernard Bruce F. M., B.Sc.(Eng.).
Birch, Bryan.
Chesters, William, Jun.
Chowla, Sada Nand.
Dawson, Stanley.
Delmar-Morgan, Edward Locker.
Diamond, John.
Dick, Thomas Pattinson, B.Sc.
Duncan, Maurice John.
Edwards, William John, B.Sc.(Eng.).
Essex, Sydney James.
Foster, John Viret.
Freebody, John William H.
Gartside, Maurice James, B.Sc.(Eng.).
Gosain, Amir Chand.
Greening, Frank Charles G., B.Sc.(Eng).
Hall, Leonard Bruce.
Hart, Stanley Haines.
Hemuss, Thomas William.
Hope, William.
Johnston, Campbell Stanley.
Kanga, Dorab Pestonjee, B.Sc.Tech.
Lee, Bernard Crossley.
Lovelock, Ralph Tweed.
MacKenzie, Murdo.
McLean, Archibald Legget.
Maiden, Frederick Hugh.
Mathur, Lakshmi Narain, B.Sc., B.Eng.
Murphy, Arthur Yoakley.
Nathan, Maurice Elias.
Paul, Robert Hoisington, B.A., B.Sc.(Eng.).
Pearson, Albert Edward.
Pellow, James.
Radford, John Samuel.
Richardson, John Eric, B.Eng.
Rippon, Edward Collingwood.
Sayers, James Edmund, B.Sc.
Shrimpton, Herbert John D., B.Sc.
Sirry, Mostafa, B.Sc.
Skowron, Arthur, B.Sc.(Eng.).
Smith, Frederick George, B.Sc.(Eng.).
Smith, Stanley Perceval, B.Sc.(Eng.).
Sutton, Richard Thomas.
Thompson, Sydney Whitehead.
Vajramushti, Vyankatesha Ramachandra, B.Sc.(Eng.).
White, Hubert Robert C.
White, Stuart, B.Sc.(Eng.).
Wright, John Dingwall, B.Eng.
Yates, George Arthur.
Young, Ernest Herbert H.

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- vol. 3. Practical wiring works, by F. C. Raphael. Switching, by F. W. Andrews. Primary and secondary cells, by W. S. Ibbetson.
- vol. 4. Motor starters and regulators —— Private power plant, by H. Cotton. Electric signs, by G. A. Wedge. Estimating, by H. R. Taunton.
- vol. 5. Heating and cooking, by J. F. Stanley. Converting plant, by P. Kemp. Electric bell, alarm, and clock systems, by J. F. Corrigan.
- vol. 6. Electric lifts, by L. S. Atkinson. Lamps and illumination, by J. S. Dow. House and office telephones, by T. Sherratt.
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BUSHING INSULATORS FOR OUTDOOR TRANSFORMERS.

By W. J. JOHN, B.Sc., Associate Member.

(*Paper first received* 3*rd November*, 1930, *and in final form* 2*nd October*, 1931; *read before* THE INSTITUTION 3*rd December*, 1931, *and before the* NORTH-WESTERN CENTRE 5*th January*, 1932.)

SUMMARY.

The paper has four sections which discuss:—(1) The electrical characteristics which outdoor bushings should possess for satisfactory operation; (2) the testing of bushings; (3) the factors which control the design of bushings; and (4) types of bushings.

The paper deals particularly with bushings for outdoor transformers, but other bushings are briefly considered, e.g. those for oil circuit-breakers and also wall and roof bushings and cable terminations.

(1) *Electrical Characteristics.*

Desirable characteristics are discussed, the bushing being considered firstly as part of a transformer and therefore subject to all the transformer tests, and secondly as part of a transmission line and therefore subject to over-potentials which originate in the line.

Bushing as part of transformer.—The transformer with its bushings is assumed to be tested in accordance with B.S.S. No. 171—1927. Values are thus obtained for the 1-minute test voltages, particularly for 3-phase transformers with neutral earthed or insulated. Methods of bushing failure by flash-over and by puncture are considered, and figures are given for the various flash-over voltages, viz. air-end flash-over under dry and wet conditions and also oil-end flash-over.

Bushing as part of transmission line.—The transmission-line insulators are assumed to conform to the test requirements of B.S.S. No. 137—1930. The magnitudes of over-potentials which originate in the line and impinge on the transformer are considered. A law is given for the relative strengths of transformer insulation as measured by 1-minute test values and as measured under impulse conditions. The law is used to obtain flash-over characteristics for "weak links" in the line insulation. Recommended bushing flash-over characteristics are given.

The two sets of flash-over figures now obtained are considered together and final recommendations are made for bushing characteristics. For comparison the characteristics are given for bushings to Central Electricity Board requirements and also for bushings in accordance with the new British Standard Specification B.S.S. No. 223—1931.

Indoor transformer bushings; bushings for oil circuit-breakers and cable terminations; wall bushings; roof bushings.—The differences between these and outdoor transformer bushings are considered. Suggested characteristics are given.

Lightning arrestors.—These are briefly considered.

(2) *Testing of Bushings.*

Dry flash-over voltage.—Effects of barometric pressure, air temperature and humidity.

Wet flash-over voltage.—The effects of intensity of rainfall and resistivity of water are considered.

Duration of test.—Figures are given of the times taken to carry out various tests.

Temperature-rise of metal parts.—The use of thermo-couples to measure temperature-rise is described, and results of typical tests are given.

Temperature-cycle test.—This test is described.

(3) *Design of Bushings.*

Features of electrical design are first considered.

Temperature; duration of test; shape of electrodes.—These factors are considered as affecting the electric strength of insulation.

Permissible voltage gradients.—These are given for porcelain, varnish-paper insulation, air, oil, solid compound, and semi-fluid compound.

Laws of corona and puncture.—These laws are developed for bushings having two or three different dielectrics.

Flash-over voltages.—Curves are given connecting axial lengths over bushing surface with flash-over voltages for dry, wet and under oil conditions.

Heating of bushings.—Brief consideration is given to the heating of the centre conductor, allowing for skin effect, and to the heating of the earth flange due to hysteresis and eddy-current losses.

Features of mechanical design and construction are also considered.

Clamps.—For dealing with large currents.

Joints.—The making of oil-tight and weather-tight joints.

(4) *Types of Bushings.*

The following types are described and discussed:—All-porcelain air-core; compound-filled; oil-filled; condenser; all-porcelain multi-tubular; all-porcelain multi-tubular embodying condenser feature.

The incorporation of a current transformer as part of the bushing is described, and capacitance coupling is briefly considered.

In conclusion the following Appendices are given:—

I. Development of law connecting dry and wet flash-over voltages.
II. Corona formation in air-core porcelain bushings.
III. Radial electrostatic stresses in bushings having three different dielectrics.
IV. Statistics of heavy rainfall.

The increasing use of outdoor substations has necessitated the development of transformers suitable for use in unprotected positions out-of-doors. In the majority of cases the transformers are connected to overhead transmission lines, the junction between transformer winding and overhead line being at the terminals where the winding is brought out of the transformer tank. These terminals are called "outdoor-type bushing insulators" or briefly "outdoor bushings." For connection to overhead lines the bushing is usually mounted on the top of the transformer tank and is of the general shape shown in Fig. 1.

The distinctive features of such bushings are mainly due to the facts that they must:—

(i) Have certain electrical characteristics because of their connection with the overhead transmission line;

TABLE 1.

Type	Service voltage, kV	Test voltage from separate source, kV	Induced-voltage test, kV
Fully insulated transformer	V	$2V + 1$	$2V$
Transformer with graded insulation	V	—	$2 \cdot 73V$
Transformer subjected to increased test pressures..	V	(i) $2 \cdot 73V + 1$ (ii) $2 \cdot 8V + 1 \cdot 4$	—

TABLE 2A.

Tests on Individual Single-Phase Transformers Comprising a 3-phase Bank.

(In accordance with B.S.S. No. 171—1927.)

Fully Insulated				Graded Insulation		
Connection	1-minute test			Connection	Induced-voltage 1-minute test	
	Separate source to earth	Induced voltage			Between terminals	To earth
		Between terminals	To earth			
3-phase star ..	$2V + 1$	—	—	3-phase star. Neutral earthed	$2 \cdot 73V$	$1 \cdot 58V$
3-phase delta ..	$2V + 1$	—	—	3-phase delta. One terminal earthed	$2 \cdot 73V$	$2 \cdot 73V$

TABLE 2B.

Tests on Complete Transformer Units.

(In accordance with B.S.S. No. 171—1927.)

Fully Insulated					Graded Insulation		
Transformer unit	Service voltage, V	1-minute test voltage			Transformer unit	Induced voltage. 1-minute test	
		Separate source to earth	Induced voltage			Between terminals	To earth
			Between terminals	To earth			
3-phase star	Voltage between any two of principal conductors	$2V + 1$	$2V$	$1 \cdot 16V$	3-phase star. Neutral earthed	$2 \cdot 73V$	$1 \cdot 58V$
3-phase delta	Voltage between any two of principal conductors	$2V + 1$	$2V$	$1 \cdot 16V$	3-phase delta. One terminal earthed	$2 \cdot 73V$	$2 \cdot 73V$
2-phase. One common terminal	Voltage between conductors of one phase	$2 \cdot 8V + 1 \cdot 4$	$2 \cdot 8V$	$1 \cdot 4V$	2-phase. Common terminal earthed	$3 \cdot 86V$	$2 \cdot 73V$
Single-phase (on insulated system)	Voltage between the two principal conductors	$2V + 1$	$2V$	V	Single-phase. One terminal earthed	$2 \cdot 73V$	$2 \cdot 73V$

(ii) Insulate the leads connected to them when rain is falling on the transformer;

(iii) Be absolutely watertight so that it is impossible for moisture to get into the transformer oil through the bushing; and

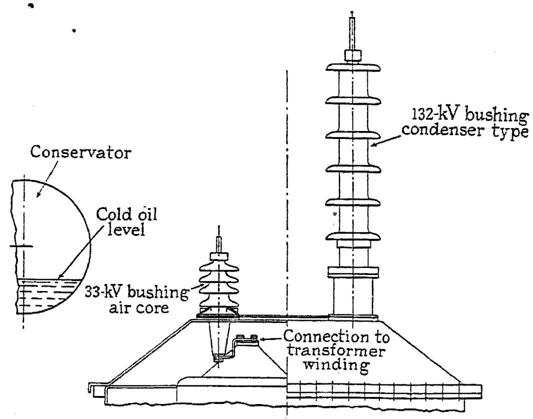

132-kV bushing condenser type
Conservator
Cold oil level
33-kV bushing air core
Connection to transformer winding

FIG. 1.—Top of transformer tank, showing outdoor bushings.

(iv) Be absolutely oil-tight. Outdoor transformers are usually arranged to work with a conservator so that there is a hydrostatic oil pressure at all parts, and the bushing must not permit of oil leakage under these conditions.

(1) ELECTRICAL CHARACTERISTICS OF BUSHINGS.

THE BUSHING REGARDED AS PART OF THE TRANSFORMER.

The bushing must withstand whatever tests are applied to the completed transformer. In this country the tests for transformers are governed by B.S.S. No. 171—1927 ("Electrical Performance of Transformers for Power and Lighting"). In that Specification different tests are laid down depending upon whether the transformer is of the "fully-insulated" type or of the "graded-insulation" type. Certain other tests are demanded for transformers subjected to increased test pressures.

Three-phase transformers with graded insulation have to withstand 1-minute tests in which the voltage to earth is only 79 per cent of that used with fully insulated transformers. This reduction in the test voltage means a considerable saving in transformer insulation. The electrical characteristics of the bushing should be related to the strength of the transformer insulation, so that a bushing should have different characteristics depending upon whether the transformer of which it is a part has graded insulation or not.

Bushing 1-minute tests.—The specified tests are set out in Table 1.

The diagrams of Fig. 2 show the connections necessary for carrying out the specified voltage tests. The voltage to earth which the bushing has to withstand is also indicated.

Tables 2A and 2B give the test voltages which apply in a few typical cases.

Considering from this point only 3-phase transformers, with neutral earthed or insulated, the 1-minute test voltages to earth are:—

Neutral earthed .. .. $1\cdot 58V$
Neutral insulated .. .. $2V + 1$

Table 3 shows the figures given by these equations for the ordinary standard voltages.

Table 4 is obtained by adopting as reasonable a 10 per cent higher test voltage for the bushings than for the complete transformer.

These voltages should be withstood by the bushings without distress. Slight corona formation on flange or top-cap is not objectionable, but definite streamers over the porcelain surface should be absent.

If the outdoor transformer is to work under rain with the same factor of safety on all its parts as normally holds for an indoor transformer, then the complete transformer must withstand the 1-minute test figure under *wet* conditions. The 1-minute test pressures of Table 4 should thus apply to wet as well as to dry conditions.

TABLE 3.

1-*Minute Tests on 3-phase Transformers.*

V (kV)	3·3	6·6	11	22	33	44	66	132	220
$1\cdot 58V$ (kV) ..	5·2	10·4	17·4	34·8	52·2	70	104	208	348
$2V + 1$ (kV)..	7·6	14·2	23	45	67	89	133	265	441

TABLE 4.

1-*Minute Test Pressures for Bushings* (*Dry and Wet*).

V (kV)	3·3	6·6	11	22	33	44	66	132	220
$\frac{11}{10}$ ($1\cdot 58V$) (kV)	5·8	11·5	19·1	38·3	57·5	76·5	115	230	383
$\frac{11}{10}$ ($2V+1$) (kV)	8·4	15·6	25·3	49·5	73·8	98	147	292	485

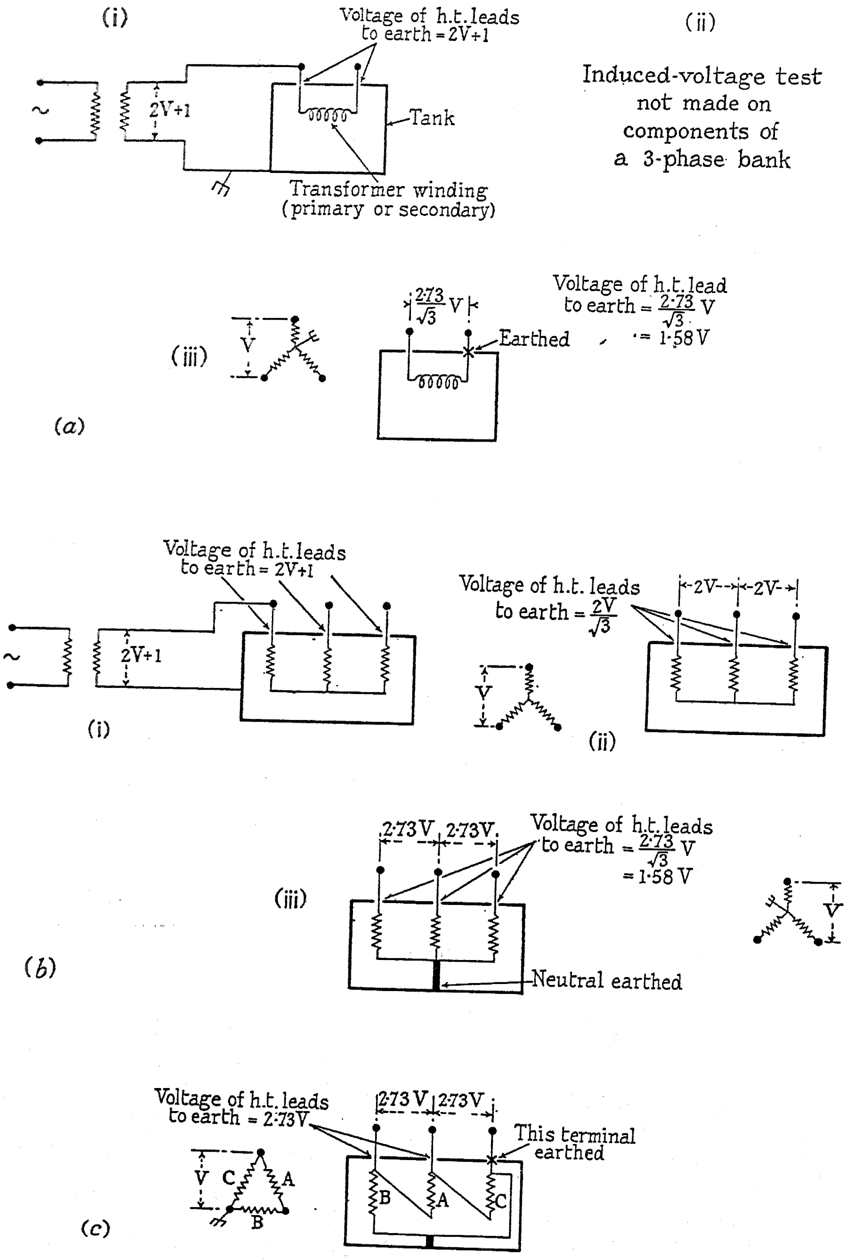

(i)
Voltage of h.t. leads to earth = 2V+1
(ii)
Induced-voltage test not made on components of a 3-phase bank
~
2V+1
Tank
Transformer winding (primary or secondary)
(iii)
V
$\frac{2{\cdot}73}{\sqrt{3}}$ V
Earthed
Voltage of h.t. lead to earth = $\frac{2{\cdot}73}{\sqrt{3}}$ V = 1·58 V
(a)
Voltage of h.t. leads to earth = 2V+1
~
2V+1
(i)
Voltage of h.t. leads to earth = $\frac{2V}{\sqrt{3}}$
2V 2V
V
(ii)
2·73 V 2·73 V
Voltage of h.t. leads to earth = $\frac{2{\cdot}73}{\sqrt{3}}$ V = 1·58 V
(iii)
V
Neutral earthed
(b)
Voltage of h.t. leads to earth = 2·73 V
2·73 V 2·73 V
This terminal earthed
V
C
A
B
(c)

FIG. 2.

(a) 1-minute tests on single-phase transformer components of a 3-phase star-connected bank [voltage (kV) between lines = V].
(i) Separate source test to earth. Fully insulated. (iii) Graded-insulation induced-voltage test. Neutral earthed.
(b) 1-minute tests on 3-phase star-connected transformer unit [voltage (kV) between lines = V].
(i) Separate source test to earth. Fully insulated.
(ii) Induced-voltage test. Fully insulated.
(iii) Graded-insulation induced-voltage test. Neutral earthed.
(c) 1-minute graded-insulation induced-voltage test on 3-phase delta-connected transformer unit. One terminal earthed.

Bushing flash-over voltages.—If the voltage is raised above the 1-minute figures, then at a certain voltage the bushing will fail to insulate owing to one of the following reasons:—

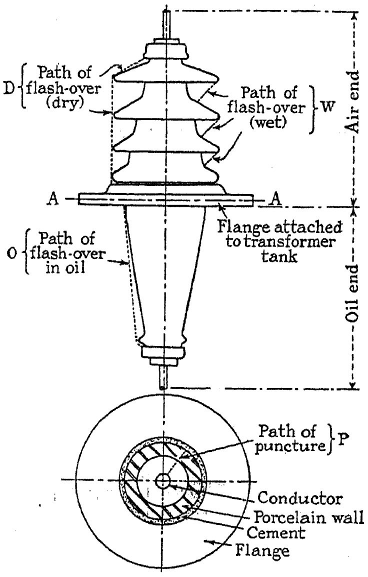
(1) There may be an axial flash-over from the top cap of the bushing to the flange under dry conditions (D in Fig. 3).

(2) The same thing may happen under wet conditions (W in Fig. 3).

(3) There may be flash-over from flange to bottom cap along the oil-immersed portion of the bushing (O in Fig. 3).

(4) There may be radial puncture of the insulation (P in Fig. 3).

As air-end flash-over is the least serious of these failures, the transformer bushing should be designed to flash over at the air-end at a much lower voltage than it flashes over at the oil end or punctures. The sequence of oil-end flash-over and puncture is immaterial, since the bushing will never fail in either of these ways under ordinary service conditions, and no useful purpose is served by specifying that flash-over at the oil end must precede puncture. It is difficult to obtain consistent results for flash-over at the oil end unless the greatest care is taken both with the oil and with the surface of the porcelain. The designer usually makes the bushing longer at the oil end than may be thought necessary so as to guard against the possibility of the oil or the porcelain surface getting dirty in service. This is good practice, but if it is specified that flash-over at oil end shall precede puncture, then, should the conditions of porcelain surface, etc., happen to be favourable for high flash-over, radial puncture may occur before oil-end flash-over. A far better procedure is to specify a voltage well above the air-end flash-over voltages, which the bushing must stand when totally immersed in oil before either puncture or oil-end flash-over occurs.


D { Path of flash-over (dry)
Path of flash-over (wet) } W
Air end
A
A
O { Path of flash-over in oil
Flange attached to transformer tank
Oil end
Path of puncture } P
Conductor
Porcelain wall
Cement
Flange

Section at AA

FIG. 3.—Paths of discharge in various ways of bushing failure.

Definite values for bushing flash-over characteristics can be found by deciding how much greater should be the wet and the dry flash-over voltages than the 1-minute test figures, and further how much greater should be the oil-end flash-over or puncture than the air-end flash-over voltages.

Dry and wet flash-over voltages at air end.—These are not independent, since in the design of the bushing the fixing of the wet flash-over voltage also fixes the minimum dry flash-over voltage, and this minimum is usually greater than the wet flash-over voltage. The more economical the design the more nearly equal are the two flash-over voltages. This matter is discussed in Appendix I, and the law connecting the wet and minimum dry flash-over voltages is there proved (subject to certain assumptions) to be

Minimum dry flash-over voltage (kV) = 0·94 wet flash-over voltage + 20.

Allowing a little margin above the actual minimum figures, a reasonable dry flash-over voltage to be associated with a given wet flash-over voltage may be obtained from the law

Dry flash-over voltage (kV) = wet flash-over voltage (kV) + 20.

Hence, in obtaining definite figures for dry and wet flash-over voltages at the air end, it will be assumed that sufficient margin between *wet* flash-over and 1-minute figures is obtained by making the flash-over voltage 20 per cent greater than the 1-minute figures up to 33 kV and tailing off uniformly to 10 per cent greater at 220 kV. The *dry* flash-over figures are obtained by using the above law.

Oil-end flash-over voltage.—The oil-end flash-over voltage should be as much greater than the air-end flash-over voltage as is possible without unduly increasing the size and cost of the bushing. Reasonable figures are obtained by making the voltage which the oil-immersed end can withstand without flash-over, 50 per cent greater than the air-end dry flash-over up to 33 kV and tailing off to 20 per cent greater at 220 kV.

Bushing characteristics.—The electrical characteristics of transformer bushings based on the lines discussed are:—

Neutral Insulated.

1-minute wet test $= \frac{11}{10}(2V + 1) = 2\cdot 2V + 1\cdot 1$
1-minute dry test $= 2\cdot 2V + 1\cdot 1$

Flash-over voltage (wet):—

(*a*) Up to 33 kV:—$2\cdot 64V + 1\cdot 3$
(*b*) Above 33 kV:—$2\cdot 38V + 9$

Flash-over voltage (dry):—

(*a*) Up to 33 kV:—$2\cdot 64V + 21$
(*b*) Above 33 kV:—$2\cdot 38V + 29$

Test voltage for flash-over at oil-end or puncture:—

(*a*) Up to 33 kV:—greater than $3\cdot 96V + 32$
(*b*) Above 33 kV:—greater than $2\cdot 69V + \cdot 72$

Similar equations can be obtained for neutral earthed.

The figures for various working voltages as obtained from these formulæ are given in Table 5.

TRANSFORMER BUSHING CONSIDERED AS PART OF THE TRANSMISSION LINE.

Travelling waves originating in the transmission line arrive at the transformer terminals, and the voltage associated with a travelling wave may be greater than normal line voltage. The influence of these over-potentials on bushing characteristics can be studied by regarding the bushing as the last insulator of the transmission line.

The transmission line will be, in the great majority of cases, an overhead line mounted on porcelain insulators. These insulators are exposed to all weather conditions as is, of course, the transformer bushing also.

The service conditions to which the line insulators are

TABLE 5.

Flash-over Voltages for Bushings. Dry, Wet, and Oil End.

(All figures are in kilovolts.)

Working voltage, kV	3·3	6·6	11	22	33	44	66	132	220
A. NEUTRAL EARTHED.									
1-minute test	5·8	11·5	19·1	38·3	57·5	76·5	115	230	383
Flash-over (wet):—									
(*a*) Up to 33 kV	6·9	13·8	23	46	69	—	—	—	—
(*b*) Above 33 kV	—	—	—	—	—	90	131	255	421
Flash-over (dry):—									
(*a*) Up to 33 kV	26·9	33·8	43·0	66·0	89	—	—	—	—
(*b*) Above 33 kV	—	—	—	—	—	110	151	275	441
Test voltage for flash-over at oil end or puncture:—									
(*a*) Up to 33 kV	40	51	65	99	134	—	—	—	—
(*b*) Above 33 kV	—	—	—	—	—	157	203	342	529
B. NEUTRAL INSULATED.									
1-minute test	8·4	15·6	25·3	49·5	73·8	98	147	292	485
Flash-over (wet):—									
(*a*) Up to 33 kV	10	18·7	30	59	88	—	—	—	—
(*b*) Above 33 kV	—	—	—	—	—	114	166	324	534
Flash-over (dry):—									
(*a*) Up to 33 kV	30	38·7	50	79	108	—	—	—	—
(*b*) Above 33 kV	—	—	—	—	—	134	186	344	554
Test voltage for flash-over at oil end or puncture:—									
(*a*) Up to 33 kV	45	58	75	119	162	—	—	—	—
(*b*) Above 33 kV	—	—	—	—	—	190	250	427	665

subjected may be divided into three main categories, viz.:—

(*a*) Service conditions associated with ordinary line voltage.
(*b*) Service conditions associated with over-voltages definitely related to the normal line voltage.
(*c*) Service conditions associated with over-voltages independent of normal line voltage.

The service conditions associated with ordinary line voltage are identical for both line and bushing insulators. Over-voltages related to the normal line voltage are produced by any change in circuit conditions, e.g. by switching. Over-voltages independent of normal line voltage are produced by lightning discharges in the vicinity of the line.

The full brunt of the over-voltages will be borne by the line insulators, and in general no over-voltage having a higher value than the surge flash-over voltage of the line insulators can reach the transformer bushings. This surge flash-over voltage is practically identical under both wet and dry conditions and is approximately twice the normal 50-cycle dry flash-over voltage.

Line-insulator characteristics.—The characteristics of line insulators are given in B.S.S. No. 137—1930 (which has recently superseded B.S.S. No. 137—1922) and the universally adopted practice is to use cap-and-pin type insulators for lines working above 33 kV.

Adopting the requirements of B.S.S. No. 137—1930, it is probable that the flash-over characteristics of the line insulators at the various working voltages will be as shown in Table 6. The figures in brackets [e.g. (40)] are in accordance with B.S.S. No. 137—1922. Above 33 kV there is probably no difference in the numbers of units required in cap-and-pin insulator strings whichever specification is worked to.

In Table 6 the puncture voltages for cap-and-pin insulator strings have been omitted since these are abnormally high compared with the flash-over figures.

These line-insulator characteristics indicate the flash-over figures which at various working voltages give reasonable commercial immunity from an excessive number of shut-downs due to over-voltages. Further, if transformers are connected directly to lines thus insulated the magnitude of the over-voltages which reach the transformers from the line cannot exceed the corresponding impulse flash-over figures.

Impulse strength of transformer winding insulation.—A transformer terminal is a point of discontinuity, and, since the surge impedance of a transformer is greater than that of an overhead line, the voltage produced at the transformer terminals is greater than the voltage E

associated with the incoming wave. In the limit, regarding the transformer as constituting a break in the circuit, the voltage at the terminals becomes $2E$. Transformer bushing and transformer winding insulation must therefore, in the absence of protective devices, be capable of withstanding an impulse voltage which is definitely greater than that of the incoming wave. It does not necessarily follow that transformer insulation which is able to withstand the 1-minute test voltages set out in Table 3, will without increase also withstand the impulse voltages which arrive at the terminals, the magnitude of these impulses being limited by the flash-over voltage of the line insulators and enhanced by reflection phenomena. The insulation of the transformer windings is much stronger under impulse than under ordinary 1-minute test conditions, and operating experience has proved that transformers with insulation sufficient to withstand the 1-minute tests for *fully insulated* transformers set out in B.S.S. No. 171—1927 will also withstand whatever impulse voltages are passed on by line insulators to B.S.S. No. 137—1922. When transformers have had reduced insulation a certain amount of trouble has been experienced. In the absence of any more definite information this operating experience can be made the basis of a law connecting 1-minute transformer tests and maximum permissible line-insulator flash-over voltages. The law is

$$B = 1\cdot39\,T + 27\cdot7$$

where B = 50-cycle dry flash-over voltage of line insulators (kV),
T = 1-minute test voltage applied to transformer (kV).

Using this law, Table 7 is constructed.

TABLE 6.

Probable Actual Line Insulator Characteristics.

Working voltage	Number of units in string	Flash-over voltage		Puncture voltage
		Dry	Wet	
kV		kV	kV	kV
3·3	—	(40) : 38	(20) : 17	(70) : 68
6·6	—	(50) : 44	(30) : 23	(87) : 80
11	—	(62) : 53	(39) : 32	(108) : 95
22	—	(95) : 74	(62) : 53	(166) : 130
33	—	(125) : 95	(84) : 74	(220) : 170
44	3	200	130	—
66	4	250	170	—
132	7	380	280	—
220	12	590	430	—

TABLE 7.

1-*Minute Transformer Test and Flash-over Voltage of Adjacent Line Insulators.*

Working voltage (kV)	3·3	6·6	11	22	33	44	66	132	220
(*a*) Fully insulated 1-minute test (kV)	8·4	15·6	25·3	49·5	73·8	98	147	292	485
Maximum permissible line-insulator flash-over (kV)	40	50	62	95	125	160	230	430	700
(*b*) Neutral earthed 1-minute test (kV)	5·8	11·5	19·1	38·3	57·8	76·5	115	230	383
Maximum permissible line-insulator flash-over (kV)	36	44	54	81	107	134	187	346	559
Normal line-insulator flash-over voltage (dry) (kV)	38	44	53	74	95	200	250	380	590
Bushing dry flash-over voltage from Table 5:—									
Fully insulated (kV)	30	39	50	79	108	134	186	344	554
Neutral earthed (kV)	27	34	43	66	89	110	151	275	441

It would thus appear that if line insulators conform to B.S.S. No. 137—1930 there will be danger, especially at voltages of 66 kV and above, of transformer-winding breakdown under lightning surges unless the insulation of *all* transformers is designed to stand the 1-minute test for fully insulated transformers, and that therefore full advantage cannot be taken of the lower tests applicable to transformers with earthed neutral. This would give rise to no great commercial hardship for voltages up to 33 kV, but for voltages of 66 kV and above it would necessitate substantial increase in transformer costs.

TABLE 8.

Suggested "Safety String" Characteristics for various Working Voltages.

Working voltage	Number of units in normal string	Flash-over voltages of normal string		Number of units in safety string	Flash-over voltages of safety string	
		Dry	Wet		Dry	Wet
kV		kV	kV		kV	kV
66	4	250	170	3	200	130
132	7	380	280	6	340	245
220	12	580	430	10	510	380

Weak links in line insulation.—It is for voltages of this order (66 kV and above), and when using transformers with earthed neutral, that the introduction of a "weak link" in the transmission line insulation should be considered. Transmission-line engineers cannot be expected to agree to any wholesale reduction in line-insulator characteristics, but they may agree to permit a weak spot in the line insulation at a point close to the transformer. For working voltages of 66 kV and above, the line insulation usually consists of strings of cap-and-pin type insulators and the weak link can be provided by omitting one or more units from the normal string.

Suggestions for safety string characteristics are given in Table 8.

An examination of Table 7 will show that, with weak links having these characteristics, the transformer insulation need not be increased beyond that necessary for the 1-minute test.

The great argument in favour of the use of safety strings is that it enables the normal line insulators to comply with B.S.S. No. 137—1922 or B.S.S. No. 137—1930, and at the same time full advantage can be taken of the reduced transformer tests of B.S.S. No. 171—1927 when the neutral is earthed.

Bushing Characteristics as related to Strength of Transformer Winding Insulation.

In the manner which has been discussed the transformer is protected by line-insulator flash-over from all surges above a certain magnitude. The surges which now arrive at the transformer will not cause immediate breakdown of the transformer winding insulation, but surges, even when of limited magnitude, can do damage, and the time during which they persist should be made as short as possible. The bushing should in all cases be weaker than the insulation of the transformer winding, so that, as far as may be practicable, surges are released by the flashing-over of the bushing. The duration of the over-voltage stress on the transformer insulation is then limited to the time required to cause the bushing to flash over. Regarded in this way, the flash-over characteristics of the bushing should be made as low as possible; the lower it is made the greater will be the factor of safety of the transformer winding.

It is not uncommon to find specifications which stipulate that the bushings must have flash-over characteristics equal to those of the line insulators. Others specify bushing characteristics somewhat in excess of the line insulators. Such fixing of dry flash-over characteristics should be carefully considered from the point of view that every increase in dry flash-over voltage necessitates either increased strength of trans-

TABLE 9.

Recommended Bushing Characteristics.

Working voltage (kV)	3·3	6·6	11	22	33	44	66	132	220
A. NEUTRAL EARTHED.									
Flash-over voltage (dry) kV) ..	38	44	53	79	108	134	151	275	441
Flash-over voltage (wet) (kV) ..	17	23	32	59	88	114	131	255	421
Test voltage oil end (kV)	68	80	95	130	170	190	210	342	529
B. NEUTRAL INSULATED.									
Flash-over voltage (dry) (kV) ..	38	44	53	79	108	134	186	344	554
Flash-over voltage (wet) (kV) ..	17	23	32	59	88	114	166	324	534
Test voltage oil end (kV)	68	80	95	130	170	190	250	427	665

former insulation (and this may be a costly process) or a deliberate acceptance of reduced factor of safety on the transformer winding insulation. The argument commonly put forward in favour of equality of line and bushing flash-over is that a bushing flash-over is rather more serious than a line-insulator flash-over and should be avoided. If this attitude be adopted then the bushing flash-over must be made much greater than the line insulator flash-over (in the limit twice as great) because of reflection of incoming voltage waves at the transformer terminals. Equality of the two voltages cannot prevent bushing flash-over preceding line-insulator flash-over. In the opinion of the author no sufficiently useful purpose is served by demanding bushing flash-over characteristics for 66 kV and above, in excess of those given in Table 5, where the characteristics are fixed having regard only for the 1-minute tests. For voltages of 33 kV and below, however, bushings can be given line-insulator flash-over characteristics, since this will not unduly increase their size or the cost of transformer insulation.

Bushing characteristics.—The procedure advocated would give final values for bushing characteristics as shown in Table 9, which has been compiled from Tables 5 and 6. It will be seen that up to 44 kV no distinction is made between neutral earthed and insulated. The advantages of this from a standardization point of view are obvious, and it is felt that the correct procedure is to increase transformer insulation rather than to decrease bushing characteristics when the neutral is earthed.

The figures given in Table 9 should be regarded as minimum ones, and higher figures may be used should the economics of the situation justify it and the strength of the transformer insulation allow it.

Comparison of Recommended Bushing Characteristics.

A British Standard Specification (B.S.S. No. 223—1931) dealing with high-voltage bushings has been recently published. It will be of interest to include (Table 10) a comparison of bushing characteristics as given in Table 9 with those put forward in B.S.S. No. 223—1931 and also with those occurring in Central Electricity Board Specifications.

Lightning Arrestors.

These are additional insurances against failure of any part of the transformer insulation due to repeated impulse voltages below line insulator flash-over. When a lightning arrestor is installed no reduction in bushing characteristics can be made where these are fixed by the 1-minute test.

Certain other protective devices such as condensers and choking coils arranged in various ways have the property of definitely reducing by a calculable amount the over-voltages passed on to the transformer. If the impulse flash-over voltage of the weakest line insulator is E and the protective device passes on a fraction kE, then the transformer insulation will have an increased factor of safety. As for lightning arrestors, no reduction in bushing characteristics can be made in cases where these are fixed by the 1-minute test.

Bushings for Indoor Transformers; Oil Circuit-Breakers and Cable Terminations; Wall Bushings; Roof Bushings.

These bushings differ only in minor details from the outdoor transformer bushings already discussed so far as desirable electrical characteristics are concerned. Fig. 4 shows the various bushings as they will be located in service.

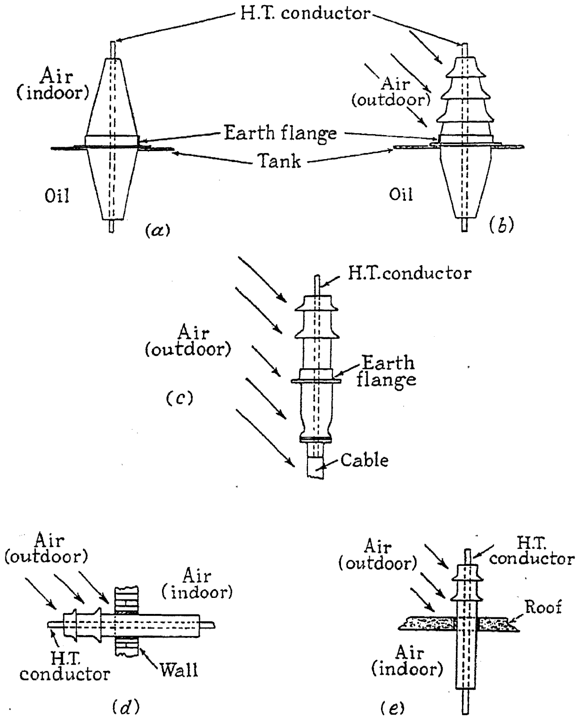


FIG. 4.—Various bushings.

(a) Indoor transformer bushing.
(b) Outdoor circuit-breaker bushing.
(c) Cable termination.
(d) Wall bushing.
(e) Roof bushing.

Indoor transformer bushings.—For these the wet flash-over figures are not relevant. Indoor transformers are tested to the same 1-minute figures as are outdoor ones, so Table 4 will still hold. The *wet* flash-over figures of Table 5 should become *dry* flash-over voltages, and the oil-end flash-over or puncture voltage can be made 50 per cent greater than air-end flash-over up to 33 kV and then reduced uniformly to 20 per cent greater at 220 kV. This gives the figures in Table 11.

If the transformer is connected to an overhead line through a wall or roof bushing, then, as discussed for the outdoor type, the bushing should be given line-insulator characteristics up to about 33 kV, as shown in Table 12.

Switchgear and cable terminations.—The relevant British Standard Specification is B.S.S. No. 116—1929, the 1-minute dry test being $2\frac{1}{4}V + 2$, and a 30-second wet test of $2V + 1$.

Proceeding in exactly the same manner as for outdoor transformer bushings, Table 13 gives recommended characteristics for switchgear bushings and for cable terminations.

The figures in brackets give the recommendation of B.S.S. No. 223—1931.

Wall and roof bushings.—Here the only difference from outdoor oil circuit-breaker bushings is that the inside portion instead of being in oil is in the air inside a building and therefore not exposed to rainfall. The sequence of failure should be:—(1) Flash-over outside end (wet), (2) flash-over outside end (dry), (3) flash-over at inside end or puncture (dry). The characteristics, therefore, should be those given in Table 13, except that for flash-over at oil end should be substituted flash-over at inner end of bushing.

TABLE 10.

Working voltage (kV)	3·3	6·6	11	22	33	44	66	132	220
A. NEUTRAL EARTHED.									
Flash-over voltage (dry) (kV):—									
B.S.S. 223—1931	—	—	—	—	70	100	165	310	480
C.E.B.	58	58	72	110	145	—	210	340	—
From Table 9 (kV)	38	44	53	79	108	135	151	275	441
Wet test:—									
*B.S.S. 223—1931. Test voltage (kV)	—	—	—	—	55	80	125	240	375
C.E.B. flash-over voltage (kV)	35	35	45	72	97	—	175	320	—
From Table 9. Flash-over voltage (kV)	17	23	32	59	88	114	131	255	421
Oil end:—									
B.S.S. 223—1931. Flash-over voltage (kV)	—	—	—	—	81	115	190	360	550
C.E.B. flash-over voltage (kV)	75	75	100	150	200	—	250	450	—
†From Table 9. Test voltage (kV)	68	80	85	130	170	190	210	342	529
Puncture voltage specified by C.E.B. (kV)	90	90	115	200	230	—	300	550	—
B. NEUTRAL INSULATED.									
Flash-over voltage dry (kV):—									
B.S.S. 223—1931	20	20	38	70	100	135	210	380	580
From Table 9 (kV)	38	44	53	79	108	135	186	344	554
Wet test:—									
*B.S.S. 223—1931. Test voltage (kV)	16	16	30	55	80	101	160	300	460
From Table 9	17	23	32	59	88	114	166	324	534
Oil end:—									
B.S.S. 223—1931. Flash-over voltage (kV)	23	23	44	81	115	155	240	440	670
†From Table 9. Test voltage (kV)	68	80	95	130	170	190	250	427	665

* B.S.S. No. 223—1931 specifies a wet test having a duration of 30 seconds, and this test must be withstood without flash-over. Also, before the application of the test voltage, the bushing with 50 per cent of test voltage applied shall be sprayed for 2 minutes.

† The figures given in Table 9 are those which the bushing should withstand when totally immersed in oil without either flash-over or puncture.

TABLE 11.

Indoor Transformer Bushings.

Working voltage (kV)	3·3	6·6	11	22	33	44	66	132	220
A. NEUTRAL EARTHED.									
$\frac{11}{10}$ (1·58V)	5·8	11·5	19·1	38·3	57·5	76.5	115	230	383
Dry flash-over voltage (kV)	6·9	13·8	23	46	69	90	131	255	421
Test voltage oil end (kV)	10·4	20·7	34·5	69	103	126	173	315	505
B. NEUTRAL INSULATED.									
$\frac{11}{10}$ (2V − 1)	8·4	15·6	25·3	49·5	73·8	98	147	292	485
Dry flash-over voltage (kV)	10	19	30	59	88	114	166	324	534
Test voltage oil end (kV)	15	28	45	88	132	161	220	400	641

(2) TESTING OF BUSHINGS.

The tests made on a bushing should have for their object the determination of the ability of the bushing to give satisfactory performance under working conditions. The severity of the tests should not be increased above what is necessary to ensure this.

TABLE 12.

Indoor Transformer Bushings. Recommended Characteristics.

Working voltage (kV)	3·3	6·6	11	22	33	44	66	132	220
A. NEUTRAL EARTHED.									
Dry flash-over voltage (kV)	38	44	53	74	108	135	151	255	421
Test voltage oil end (kV)	68	80	95	130	170	190	210	315	500
B. NEUTRAL INSULATED.									
Dry flash-over voltage (kV)	38	44	53	74	108	135	166	324	534
Test voltage oil end (kV)	68	80	95	130	170	190	220	400	640

TABLE 13.

Switchgear Bushings and Cable Terminations. Recommended Characteristics.

Working voltage (kV)	3·3	6·6	11	22	33	44	66	132	220
Flash-over voltage (dry) (kV)	38 (20)	44 (28)	53 (38)	79 (70)	108 (100)	135 (135)	186 (210)	365 (380)	605 (580)
Flash-over voltage (wet) (kV)	17	23	32	59	88	114	166	345	585
Test voltage oil end (kV)	68 (23)	80 (32)	95 (44)	130 (80)	170 (115)	190 (155)	250 (240)	435 (440)	725 (670)

The following are the most important tests usually made on transformer bushings when separate from the transformer:—

(*a*) The bushing mounted as in service is tested for flash-over voltage under dry conditions.
(*b*) The bushing is tested for flash-over under wet conditions.
(*c*) The bushing is totally immersed in oil and tested for flash-over at oil end, or puncture.
(*d*) The bushing is subjected to a test to determine the temperature-rise of the various parts when carrying its rated current.
(*e*) The bushing complete with all its metal fittings is subjected to a temperature-cycle test.

Some points of interest concerning these tests will now be discussed.

DRY FLASH-OVER VOLTAGE.

The dry flash-over voltage of a bushing is affected by a number of variables, the chief being (i) temperature of atmosphere, (ii) barometric pressure, and (iii) humidity of atmosphere. The effects of temperature and barometric pressure have been investigated by several observers, notably by Peek. The results obtained may be summarized thus:—

If V = flash-over voltage at 25° C. and 76 cm barometric pressure, and pV = flash-over voltage at t° C. and b cm barometric pressure, then p is found to be very approximately equal to δ, where δ = relative air density $= 3\cdot92\,b/(273 + t)$.

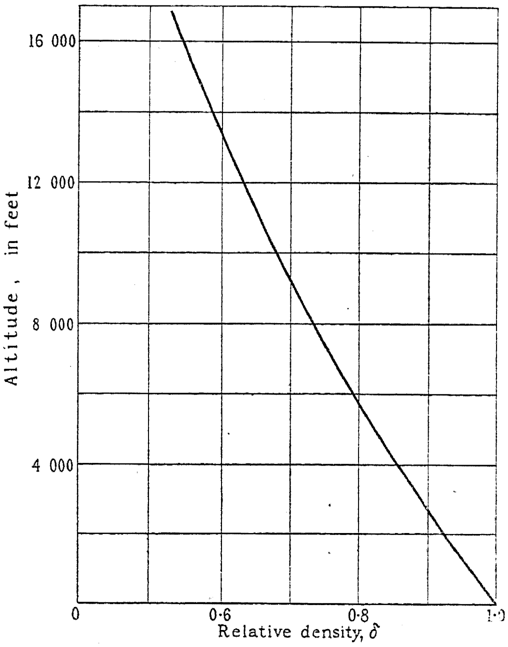


FIG. 5.—Variation of air density with altitude.

Actually the flash-over voltage will always be somewhat greater than δV. Values of δ for various altitudes are given in Fig. 5, the temperature being 25° C.

The effects of humidity have not been investigated to the same extent, but it appears that the dry flash-over voltage increases with increasing humidity up to a certain maximum and that further increase causes a reduction of the flash-over voltage. The effect is shown by Fig. 6 taken from a recent paper by Goodlet.*

Table 14 gives a typical set of flash-over figures taken on a 33-kV bushing over a period of several days.

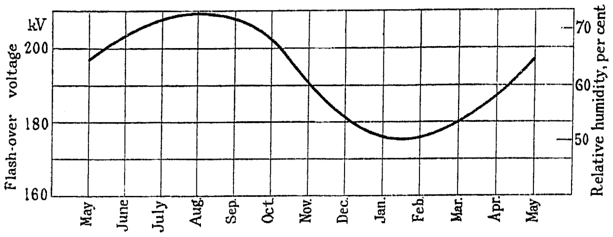


FIG. 6.—Seasonable variation of relative humidity and flash-over of high-voltage bushings.

The humidity is calculated in the ordinary way from readings of wet- and dry-bulb thermometers, but a whirling type of hygrometer should be used as considerable errors may arise with stationary types.

WET FLASH-OVER VOLTAGE.

The outdoor-type bushing must give satisfactory service when exposed to rain, and to ensure this it is necessary to test it when subjected to artificial rain. The rain should be projected downwards at an angle of 45° to reproduce conditions of wind-driven rain. Two points of outstanding importance are the intensity of the rainfall and the resistivity of the water.

Intensity of rainfall.—Data are given in Appendix IV concerning rainfall as it occurs in nature. This shows that rainfall of intensities between 4 and 8 mm per minute very rarely occurs and that higher intensities can be classed as phenomenal. A rate of precipitation of artificial rain of 3 mm per minute is more than sufficient to simulate natural rainfall. Bearing on the same subject is the fact that if typical bushing insulators are subjected to rainfalls of varying intensity and if the flash-over voltage is obtained for each intensity, curves of the average shape shown in Fig. 7 are obtained. At 3 mm per minute the curve is very flat, and for rates of precipitation of 5 mm per minute and above, the flash-over is practically independent of the rate of precipitation. Hence if tests under artificial rain stipulate that the rate of precipitation is 5 mm per minute, this will ensure satisfactory operation under the most severe rain conditions with ample margin of safety.

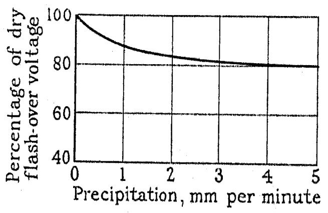


FIG. 7.—Effect of rate of precipitation of water on wet flash-over voltage.

TABLE 14.—33-*kV Bushing. Test Record of Measurements of Dry Flash-over Voltage taken on Various Dates.*

Barometric pressure	Temperature	Relative air density (calculated)	Humidity by hair hygrometer	Dry bulb	Wet bulb	Humidity (from tables)	Corona voltage	Streamers between bottom shed and earth flange	Streamers between first and second sheds	Streamers between second and third sheds	Dry flash-over voltage		Dry flash-over voltage (air density = 1, calc.)	
											First	General	First	General
mm	°C.		per cent	° F.	° F.	per cent	kV	kV	kV	kV	kV	kV	kV	kV
745·3	15·0	1·013	62	60	55·5	73·5	72	102	118	125	125	130	123·5	128·4
745·2	15·5	1·012	65	60·5	56	—	—	—	—	—	—	—	—	—
745·7	15·5	1·013	67	60·5	57	79·5	73	108	121	126	126	128	124·5	126·2
750·1	15·0	1·021	61	61·5	53	52·5	94	116	126	130	134	138	131·2	135·0
750·1	15·3	1·02	60·5	61·5	53·5	56	90	106	115	120	130	131	127·2	128·3
750·0	15·0	1·02	88	58·5	56·0	84·5	—	—	—	—	—	—	—	—
750·0	15·0	—	88	60·0	56·5	79·5	78	109	126	131	133	137	130·3	134·2
750·0	15·0	1·02	88	60	56·5	79·5	—	—	—	—	—	—	—	—
750·0	15·0	—	83	61	56	77·0	80	112	126	134	134	137	131·3	134·2
739·4	13·0	1·013	87	57	55	87	90	115	128	134	134	137	132·2	135·2
747·3	17·0	1·010	54	—	—	—	100	120	127	129	129	132	127·6	130·6
747·3	17·0	1·010	54	—	—	—	109	117	122	126	129	131	127·6	129·3
743·9	15·0	1·012	62	58	53	70	84	118	125	132	132	136	130·2	134·2

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* B. L. GOODLET: "The Testing of Porcelain Insulators," *Journal I.E.E.*, 1929, vol. 67, p. 1177.

Effect of resistivity of water on flash-over voltages obtained during artificial rain test.—The resistivity of the water used for the artificial rain has a considerable influence on the flash-over voltage of a given bushing. The easiest way to produce artificial rain is by connecting a suitable nozzle to the ordinary tap-water supply. This is unsatisfactory, however, because the resistivity of mains water often fluctuates between quite wide limits in the course of a few minutes. Tests made on the resistivity of the mains water of one large city gave values ranging from 1 500 to 11 000 ohms per cm cube in the course of a 10-minute run. Moreover, the resistivity of mains water is invariably much lower than the value appropriate for average rain water. However, the convenience of being able to draw water direct from the mains for the testing is very great, and it is the method commonly used.

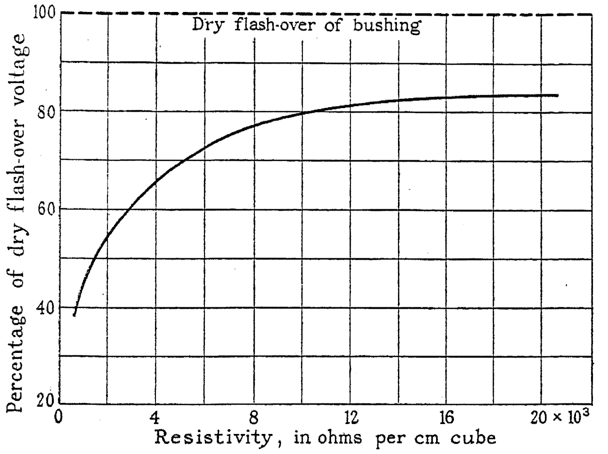

FIG. 8.—Effect of resistivity of water on wet flash-over voltage of typical bushing.

A typical curve showing the effect of resistivity of water on bushing flash-over voltage is given in Fig. 8. Above about 10 000 ohms per cm cube the effect of resistivity is small and this figure (viz. 10 000 ohms) is usually taken as the standard. Where testing under artificial rain conditions is carried out with tap water of known resistivity, standard correction curves are used to obtain the flash-over voltage corresponding to a known resistivity (usually 10 000 ohms per cm cube). Correction factors and curves used by various authorities are given in Tables 15 and 16.

Table 15 is based on a conductivity of 100 micro-siemens* per cm cube, and the reference factor is the multiplier which gives the permissible flash-over voltage in terms of this figure.

In the regulations issued by the Swiss Electrical Engineers' Association the standard resistivity is taken to be 7 000 ohms per cm cube. Table 16 gives a factor which expresses flash-overs at other resistivities in terms of the standard.

Another method of conducting rain tests, and one which is much to be preferred, is to use water having the desired standard resistivity. The water used is stored in special tanks, and by adding distilled water to ordinary tap water it is a very simple matter to obtain the required resistivity for the rain tests. The disadvantage of this method is that special storage tanks are required. Its advantages are that the water used is not subject to wide and sometimes rapid fluctuations of resistivity, and the use of correction factors is avoided. This latter advantage is very important. No simple average correction factor such as that given in Tables 15 and 16 can allow with accuracy for the various kinds of impurities occurring in tap water from different sources, and they cannot allow accurately for insulators of various shapes.

Duration of test.—The bushing must withstand without damage the normal 1-minute test which is applied to the whole transformer. Further, the various flash-over tests have to be withstood and these in general determine the amount of radial insulation required. Transformer specifications usually contain some such clause as the following:—" The bushing shall be subjected to the voltage specified in the 1-minute test figures for a period of 1 minute. The voltage shall then be increased at the rate of approximately 5 kV per second until flash-over occurs."

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* A conductivity of x micro-siemens per cm cube corresponds to a resistivity of $(1/x) \times 10^6$ ohms per cm cube.

TABLE 15.

Correction Factors for Various Water Conductivities in Wet Flash-over Tests (V.D.E. Rules).†

Conductivity, micro-siemens† per cm cube	0	50	100	150	200	250	300	350	400
Correction factor	—	1·1	1·0	0·92	0·88	0·83	0·8	0·78	0·73

† German (V.D.E.) rules for testing porcelain insulators for voltages of 1 000 and upwards.

TABLE 16.

Correction Factors for Various Water Conductivities in Wet Flash-over Tests (Swiss Electrical Engineers' Association Bulletin).‡

Resistivity (ohms per cm cube) ..	5 000	7 000	10 000	15 000	20 000	25 000	30 000
Correction factor	0·95	1	1·04	1·08	1·11	1·13	1·14

‡ Swiss Electrical Engineers' Association, Bulletin No. 12, 1923.

For bushings to Central Electricity Board specification this means that:—

6·6-kV bushings shall stand 18 kV for 1 minute, this being then raised to 58 kV in 8 seconds.

11-kV bushings shall stand 29 kV for 1 minute, this being then raised to 72 kV in 8·6 seconds.

22-kV bushings shall stand 55 kV for 1 minute, this being then raised to 110 kV in 11 seconds.

33-kV bushings shall stand 79 kV for 1 minute, this being then raised to 145 kV in 13·2 seconds.

66-kV bushings shall stand 160 kV for 1 minute, this being then raised to 210 kV in 10 seconds.

132-kV bushings shall stand 300 kV for 1 minute, this being then raised to 340 kV in 8 seconds.

These constitute the normal routine tests. In addition, various type tests are carried out on selected bushings, the most severe of these, so far as radial strength of the bushing is concerned, being the voltage applied with the whole bushing immersed in oil. This voltage is as follows for Central Electricity Board requirements:—

6·6-kV bushings shall stand a voltage raised from 18 kV to 80 kV in 12 seconds.

11-kV bushings shall stand a voltage raised from 29 kV to 100 kV in 14 seconds.

22-kV bushings shall stand a voltage raised from 55 kV to 150 kV in 19 seconds.

33-kV bushings shall stand a voltage raised from 79 kV to 180 kV in 20 seconds.

66-kV bushings shall stand a voltage raised from 160 kV to 250 kV in 18 seconds.

132-kV bushings shall stand a voltage raised from 300 kV to 450 kV in 30 seconds.

An alternative wording to the clauses governing these tests is "A voltage equal to one-third of the dry flash-over voltage shall be applied and increased as quickly as is compatible with accurate recording of the voltage attained when flash-over occurs." The advantage of this wording is that it shortens the duration of the test. Its disadvantage is its lack of definiteness as to the actual time taken.

Another alternative is "The initial voltage applied during test shall be about 75 per cent of the full voltage, which will be reached in a maximum of 15 seconds."

Temperature-Rise Test.

This test is made to determine the ability of the bushing to carry its rated current without an undue rise in temperature of any of its parts. The test becomes increasingly important as the current rating of the bushing increases. A very convenient way of measuring the temperature at various parts of the bushing is by means of thermo-couples, and a convenient thermo-couple can be made from copper and eureka wire. A terminal board may be used having a common cold junction and a common millivoltmeter which can be connected to hot junctions placed at various points. In normal testing it has been found necessary to place hot junctions at the following points:—Top of central rod; flange; middle of central rod; bottom of central rod. The results of typical tests on bushings having junctions located at these four points are given in Table 22.

Temperature-Cycle Test.

A bushing is made of constituents which have very different coefficients of expansion. Porcelain has practically zero coefficient, while the central rod, being of brass or copper, has a relatively large coefficient. In practice the bushing may be subjected to considerable and fairly rapid changes of temperature, e.g. when a bushing, having been in a hot sun, is suddenly subjected to a cool shower of rain. If there is not perfect freedom for expansion of the various constituents the bushing will be fractured under temperature changes. The object of the temperature-cycle test is to establish the ability of the bushing to behave satisfactorily when subjected to a sudden change of temperature.

The test is made by heating the bushing (complete with its metal fittings) in water which is raised to a temperature of 70° C., at which temperature it is allowed to remain for one hour. It is then taken from the hot bath and immediately totally immersed in a cold bath of ice and water maintained at a temperature of 7° C., and left there for one hour. This cycle of alternate heating and cooling is repeated three times, the bushing being kept under observation. If the bushing is going to fail it will usually do so immediately on immersion in one of the baths after having been for an hour in the other, and a crack can be heard as the porcelain fractures. If the bushing gives no obvious indication of failure at the end of the third cycle it is carefully examined for any signs of cracking and further tested by striking it a sharp blow. If intact, a clear ring will be heard. Finally, the bushing is tested to its flash-over voltage.

These tests are sometimes made on only the porcelain components of the bushing, it being impracticable to test the complete bushing (e.g. with condenser-type bushings of the outdoor type). Such a test must then of course be regarded as a test of the porcelain only, and other means must be adopted to prove the ability of the complete bushing to withstand temperature-changes.

(3) DESIGN OF BUSHINGS.

Features of Electrical Design of Bushings.

The electrical problems of bushing design are chiefly concerned with obtaining various flash-over and puncture characteristics, these characteristics being such that the sequence of breakdown in increasing order of magnitude must be:—Wet flash-over at air end—dry flash-over at air end—flash-over at oil end—puncture.

In addition to these requirements, corona should be absent from any part of the bushing at normal working voltage. Therefore the electrical problem to be solved by the bushing designer is to obtain a bushing which shall have stated puncture and flash-over voltages and which shall have the smallest axial and radial dimensions compatible with these characteristics.

A further requirement is that the bushing shall carry its full rated current without any part of it getting unduly hot. It is becoming fairly common practice to take currents of the order of 2 000 amperes from a single terminal, and the design of centre rod and earth flange for currents of this magnitude demands special attention.

Corona and puncture voltages depend upon the materials used in the manufacture of the bushing and the manner of their arrangement. The various flash-over characteristics depend upon the axial clearances from metal to earth over the surface of the bushing.

DESIGN FOR PUNCTURE AND CORONA CHARACTERISTICS.

The chief insulating materials employed in bushings are:—Air; porcelain; the various "varnish paper" insulations known by trade names such as "paxolin," "micarta," etc.; compound (solid and semi-fluid); oil. The chief function of these materials is to give radial strength against puncture, and electric strength is therefore their most important characteristic. This is affected by many factors such as temperature, duration of test, size of specimen, and shape of electrodes.

Temperature.—The temperature worked to in bushing design is 90° C., which is the maximum permissible temperature for the transformer under working conditions. Air, oil, and porcelain maintain their electric strengths practically unchanged for temperatures up to 90° C., but those of compound and of the various varnish paper insulations fall rapidly with increasing temperature.

Duration of test.—This has been discussed in the Section dealing with testing. In practice the designer usually employs data which hold for "rapidly applied voltage" conditions. The term "rapidly applied" is somewhat vague but it may be defined as "Voltage of ordinary supply frequency applied within a fairly short time." Any normal flash-over test may be considered as coming within this category.

It is necessary to ensure that whatever insulation be used it shall not be permanently damaged during testing. Oil, air, and compound, are "self-healing" in the sense that if a portion of the insulating material is overstressed for a short time and thereby damaged, its place will soon be taken by undamaged material flowing in from less highly stressed portions. Solid insulating materials are not self-healing. Damage once done is permanent and remains as a weak place in the insulation.

Shape of electrodes.—The arrangement of dielectrics in bushings corresponds approximately to concentric cylinders.

ELECTRIC STRENGTH OF TUBES OF INSULATION.

Data as to electric strength of tubes are best given in the form of curves such as those of Figs. 9 and 10.

The puncture voltage = (volts per mil) × (thickness of tube in mils).

Porcelain tubes.—The puncture strength of the tubular part of porcelain bushings (i.e. the part near the earth flange) under "rapidly applied voltage" conditions is given in Fig. 9. These figures were obtained by the author by testing a number of bushings of various dimensions.

An approximately correct equation for the puncture voltage of porcelain tubes is

$$V = 50\left\{1 + \frac{3 \cdot 5}{\sqrt{t}}\right\} r \log_e \frac{R}{r}$$

where V = puncture voltage in kilovolts,
R = outer radius (in.) of bushing at earth flange,
r = inner radius (in.) of bushing at earth flange, and
$t = (R - r)$ = thickness (in.) of wall of bushing.

Tubes made of varnish-paper insulation.—Insulations in this category are much more affected by temperature and by time of application of test than are any of the other insulations used.

It is not sufficiently accurate here to use such a vague term as "rapidly applied voltage" when fixing electric strengths. A large amount of investigation work has been done on insulations of this nature by several manufacturers, and much information as to their electric strengths is available in trade publications.

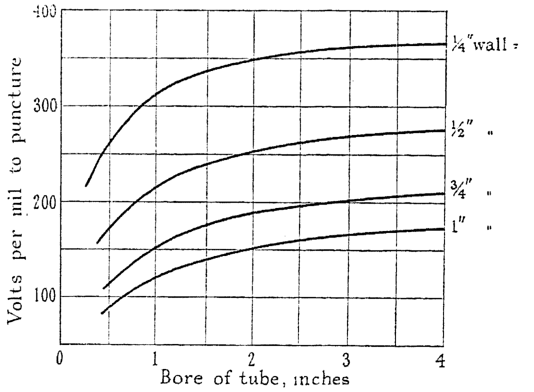

FIG. 9.—Puncture strength of porcelain tubes under rapidly applied voltage. Gradient is expressed in volts (R.M.S.) per mil.

The curves of Fig. 10 hold for paxolin varnish-paper insulation which may be taken as representative of the best of this type.

PERMISSIBLE MAXIMUM VOLTAGE GRADIENTS.

When the radial electric strength is obtained by the use of concentric cylinders of different insulating materials the above procedure is not applicable and should be replaced by methods based on permissible maximum voltage gradients. The symbol $g_{max.}$ will be used for this gradient, and $g_{max.}$ will be expressed in volts (R.M.S.) per mil, i.e. kV (R.M.S.) per inch.

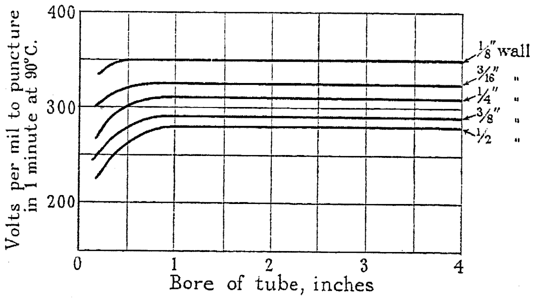

FIG. 10.—Puncture strength of paxolin tubes at 90° C. Gradient is expressed in volts (R.M.S.) per mil.

(1) *Air.*—The breakdown gradient of air as measured between concentric cylinders is not a constant but varies with the radius of the inner electrode. The law it obeys has been determined by a number of observers and is expressed by the following formula for the maximum permissible gradient in air ($g_{max.}$):—

$$g_{max.} = 55 \cdot 5\left[1 + \frac{0 \cdot 193}{\sqrt{r}}\right] \text{kV (R.M.S.) per inch}$$

where r = radius of inner electrode in inches.

The lower curve of Fig. 11 shows the variation of breakdown gradient with r, the gradient being expressed in terms of peak (not R.M.S.) volts.

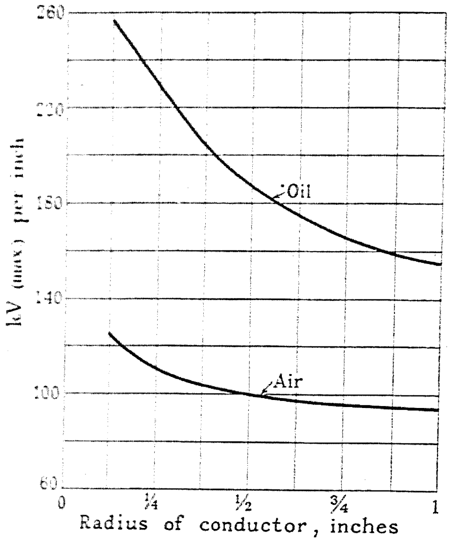

FIG. 11.—Maximum gradients permissible in air and in oil, varying with radius of conductor. Gradient is expressed in kV (max.) per inch, i.e. volts (max.) per mil.

(2) *Oil.*—Oil has similar characteristics to air. The upper curve of Fig. 11 shows the variation of breakdown gradient with r for good-quality clean transformer oil as determined by Peek. The equation for $g_{max.}$ as obtained from Fig. 11 is:—

$$g_{max.} = 64\cdot7\left\{1 + \frac{0\cdot75}{\sqrt{r}}\right\}\text{kV (R.M.S.) per inch}$$

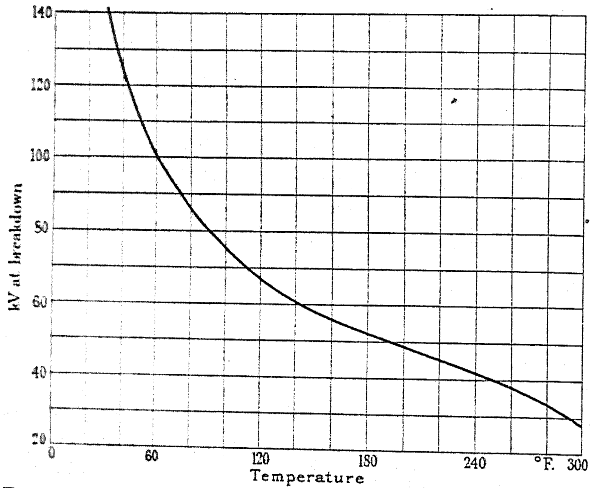

FIG. 12.—Variation of electric strength with temperature for compound. Tested between two ½-in. spherical electrodes with 0·15-in. gap. Breakdown expressed in kV (R.M.S.).

(3) *Solid compound.*—At the temperature of 90° C. compound will be almost as fluid as oil and it is to be expected that its electric strength will vary in the same manner with the radius of the inner electrode. When tested between spheres at a temperature of 90° C. good-quality high-tension compound has about the same breakdown strength as transformer oil.

Assuming that this relative strength holds for concentric cylindrical electrodes, the equation expressing the maximum permissible gradient in so-called "solid" compound at 90° C. is

$$g_{max.} = 64\cdot7\left\{1 + \frac{0\cdot75}{\sqrt{r}}\right\}\text{kV (R.M.S.) per inch}$$

Direct experimental verification of this formula has not been made, but it has been used with satisfactory results in bushing design under "rapidly applied voltage" conditions.

All compounds show considerable increase of electric strength with fall of temperature—a typical curve being shown in Fig. 12. The actual temperature of the compound in the region of the earth flange will be less than 90° C. by an amount depending upon the current being delivered by the transformer. So that if the 90° C. figure is used for the stress, there will be an indefinite but probably very considerable factor of safety under actual working conditions.

(4) *Semi-fluid compound.*—It has been found sufficiently accurate to adopt the same procedure as for solid compound and reduce all gradients by 10 per cent.

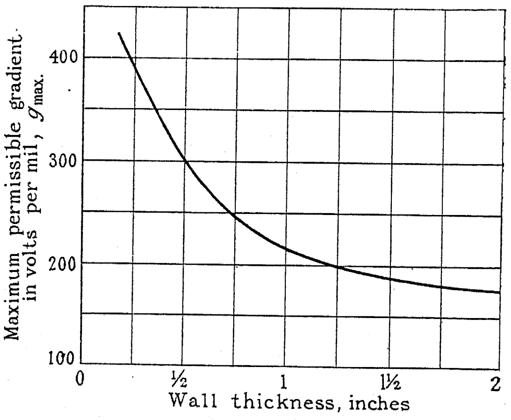

FIG. 13.—Permissible gradient in porcelain tubes. Gradient is expressed in volts (R.M.S.) per mil.

(5) *Porcelain.*—The electric strength of all solids decreases with increasing thickness.

The variation of $g_{max.}$ with t or $(R - r)$ is given in Fig. 13. This curve was obtained from the results shown in Fig. 9 by using the formula

$$g_{max.} = \frac{\text{Puncture voltage (kV)}}{r \log_e (R/r)}$$

The equation

$$g_{max.} = 50\left\{1 + \frac{3\cdot5}{\sqrt{t}}\right\}\text{kV (R.M.S.) per inch}$$

expresses approximately the relation between $g_{max.}$ and t given in Fig. 13.

(6) *Varnish-paper insulations.*—Paxolin is again taken as being typical of this class of material. Using the

curves of Fig. 10 the maximum gradient in the tube may be calculated from the concentric cylinder equation. An inspection of the time/voltage curves of Fig. 15 shows that these tubes will stand a stress of one-half the 1-minute puncture value for an unlimited time and therefore without any signs of local breakdown. This arbitrary figure (one half of the 1-minute stress) has been taken as fixing the maximum desirable stress in the insulation under the most severe test conditions.

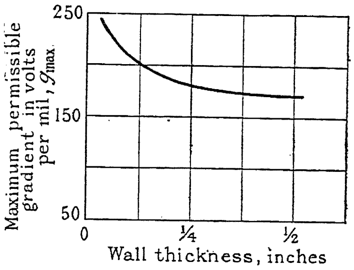

FIG. 14.—Permissible gradient in paxolin tubes at 90° C. Gradient is expressed in volts (R.M.S.) per mil.

The maximum permissible gradient is assumed to be 0·5 of the minimum voltage per mil at which the tube will puncture in 1 minute.

The curve of Fig. 14 shows the relation between wall thickness and permissible maximum stress based on these assumptions. Conditions of service and design sometimes permit the use of higher stresses—such cases must be left to the judgment of the individual designer.

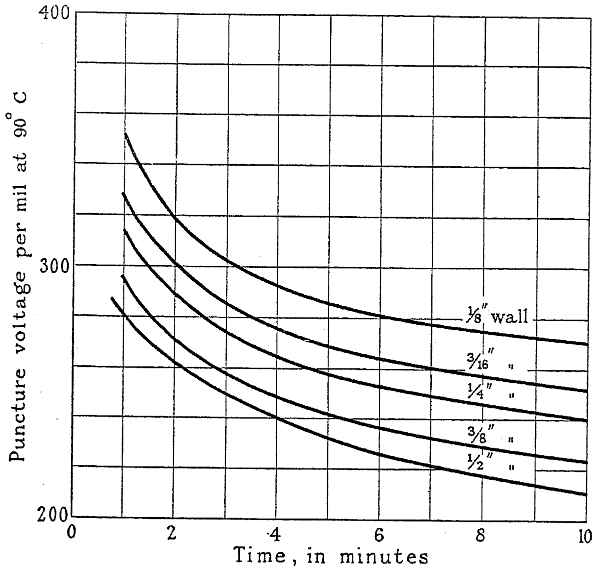

FIG. 15.—Variation with time of puncture voltage gradient for paxolin tubes. Gradient is expressed in volts (R.M.S.) per mil..

LAWS OF CORONA AND PUNCTURE.

(i) *Bushing having Two Different Dielectrics.*

Consider firstly a bushing having two different dielectrics, e.g. air and porcelain, as in the air-core bushing.

Corona on inner conductor.—The part of the bushing with the maximum radial stress is at the surface of the inner conductor in the region where it is surrounded by the earth flange. It is here that corona is most likely to occur and as its presence cannot be visually observed great care must be taken to ensure its absence. It has been found possible to do this by applying the simple formula which expresses the electrostatic stress between concentric cylinders. In its simplest form this formula states that at any distance x from the centre of an inner electrode of radius r, the voltage gradient g is:—

$$g = \frac{1}{x} \cdot \frac{v}{\log_e(r_2/r_1)}$$

where v = applied voltage between electrodes,
r_2 = radius of outer electrode, and
e = base of Napierian logarithms.

For an air-core porcelain bushing the cross-section at the earth-flange is as shown in Fig. 16.

The gradient at any radius x is now expressed as

$$g_x = \frac{1}{x} \cdot \frac{v}{\log_e \frac{r_2}{r_1} + \frac{1}{\epsilon} \log_e \frac{r_3}{r_2}}$$

where ϵ = specific inductive capacity of porcelain = 5.

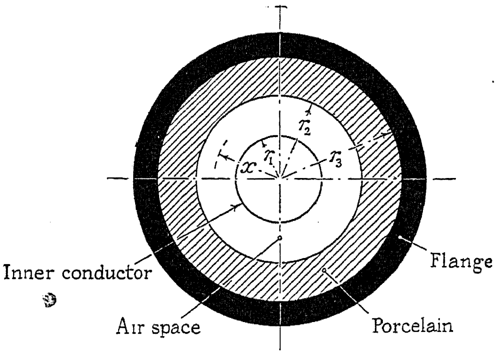

FIG. 16.—Bushing with two different dielectrics.

The maximum gradient in the air space between conductor and porcelain occurs at $x = r_1$, and is given by

$$g_a = \frac{1}{r_1} \cdot \frac{v}{\log_e \frac{r_2}{r_1} + \frac{1}{5} \log_e \frac{r_3}{r_2}}$$

Corona will occur at the surface of the inner conductor when g_a exceeds the breakdown voltage of air; this will occur at the voltage V given by

$$V = g_{max.} r_1 \left\{ \log_e \frac{r_2}{r_1} + \frac{1}{5} \log_e \frac{r_3}{r_2} \right\}$$

where $g_{max.}$ is the breakdown gradient of air.

$g_{max.}$ is not constant but varies with the radius of the inner conductor, the relation between these two quantities being given in an equation on page 312 derived from the curve of Fig. 11.

In Fig. 19 the curves show the voltages at which corona will form on inner conductors of various radii for different values of r_3, the porcelain wall thickness being 1 inch throughout. The curves show that the corona voltage increases at first with increasing radius r_1, reaches a maximum, and then diminishes. The method of determining the value of r_1 which gives the maximum voltage for given values of r_3 and r_2 is given in Appendix II, where it is shown to be the value of r_1 which satisfies the equation

$$C - 1 - \log_e r_1 = \frac{B/(2\sqrt{r_1})}{A + B/(2\sqrt{r_1})}$$

where

$$A = 55 \cdot 5;\ B = 10 \cdot 7;\quad \text{and}\quad C = \tfrac{4}{5}\log_e r_2 + \tfrac{1}{5}\log_e r_3.$$

The value chosen for r_1 should approximate to this, but as the curve is very flat in the neighbourhood of its maximum a somewhat smaller value for r_1 may frequently be used with advantage.

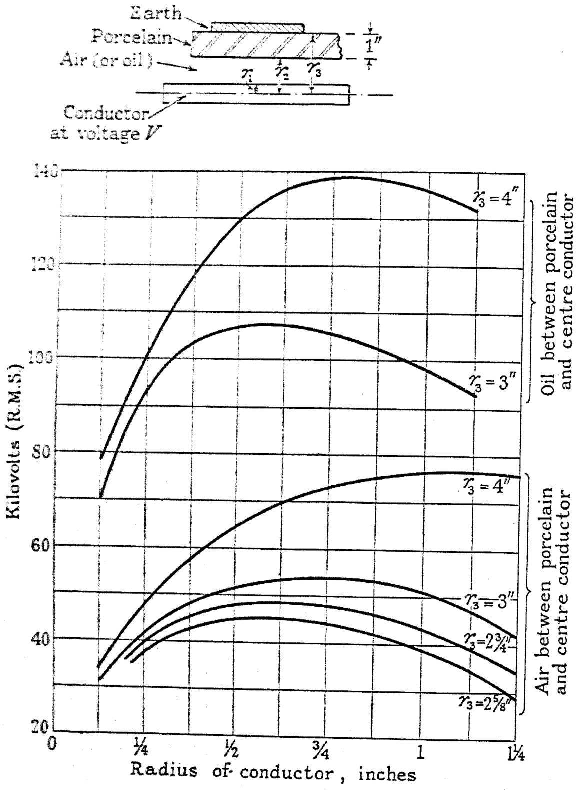

FIG. 17.—Voltage at which corona forms on centre conductor.

Puncture voltage.—When puncture occurs the air-space between porcelain and conductor is filled with corona. The conductor may now be regarded as having a radius of r_2, and the maximum gradient in the porcelain (occurring when $x = r_2$) is

$$g_a = \frac{v}{r_2 \log_e (r_3/r_2)}$$

whence $v = g_a r_2 \log_e (r_3/r_2)$.

If it is assumed that puncture of the porcelain occurs when g_a exceeds a certain figure, say $g_{max.}$, then the puncture voltage V is

$$V = g_{max.} r_2 \log_e \frac{r_3}{r_2} .$$

$g_{max.}$ is not constant for porcelain, but varies with the wall thickness as shown in the curve of Fig. 13.

Puncture strengths of porcelain tubes for various values of r_3 and r_2 are given in Fig. 9.

(ii) *Bushing having Three Different Dielectrics.*

This corresponds to the state of affairs holding in a bushing having oil or compound filling with solid insulation round the central conductor.

The relation between applied voltage v and gradient g_x at radius x where the dielectric has specific inductive capacity ϵ_x is

$$v = g_x \epsilon_x x \left[\frac{\log_e (r_2/r_1)}{\epsilon_1} + \frac{\log_e (r_3/r_2)}{\epsilon_2} + \frac{\log_e (r_4/r_3)}{\epsilon_3} \right]$$

the symbols having the meaning indicated in Fig. 18.

In Appendix III the relation between r_1 and r_2 which gives minimum stress at $x = r_1$ is calculated for fixed values of r_2, r_3, and r_4.

The relation is proved to be

$$r_1 = \frac{1}{e} r_2^{(1-\epsilon_1/\epsilon_2)} r_3^{(\epsilon_1/\epsilon_2 - \epsilon_1/\epsilon_3)} r_4^{(\epsilon_1/\epsilon_3)}$$

Consider a bushing where $r_3 = 2$ in., $r_4 = 3$ in., $\epsilon_1 = 4$ (paxolin); $\epsilon_2 = 2 \cdot 75$ (compound); $\epsilon_3 = 5$ (porcelain).

$$\text{Then}\quad r_1 = \frac{1}{2 \cdot 718} r_2^{(-0 \cdot 46)} \times 1 \cdot 585 \times 2 \cdot 408$$

$$= \frac{1 \cdot 4}{r_2^{0 \cdot 46}}$$

r_2 cannot have a greater value than r_3 (= 2 in.), which fixes the minimum value of r_1 as 1 inch. Also r_2 cannot be less than r_1, which fixes the minimum value of r_1 as 1·25 inches. The range of values for r_1 where the formula can be applied is thus very limited. It is further limited by the practical consideration that the minimum convenient commercial thickness of a wall of paxolin is about ⅛ in.

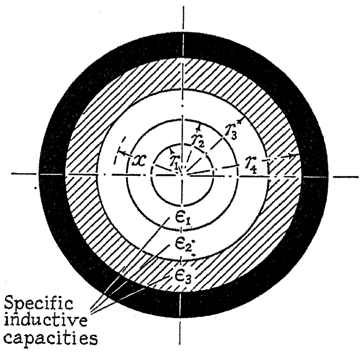

FIG. 18.—Bushing with three different dielectrics.

Corresponding values of r_1 and r_2 satisfying the equation are:—

r_1 r_2	1·05 in. 1·85 in.	1·125 in. 1·59 in.	1·225 in. 1·3 in.

For an assumed arbitrary voltage v = 100 kV (R.M.S.) the critical gradients in the various dielectrics are as set out in Table 17.

The voltage which will cause puncture is that which sets up in paxolin or porcelain a radial stress greater than the limiting stress as set out in the Section on insulating materials and shown in Table 18.

TABLE 17.

r_1	1·05 in.	1·125 in.	1·225 in.
r_2	1·85 in.	1·59 in.	1·30 in.
$g_x x \epsilon_x$	392	397	397
g at $x = r_1$ (paxolin)	93	88	81
g at $x = r_2$ (compound)	77	90	110
g at $x = r_3$ (porcelain)	39·2	39·7	39·7
g at $x = r_4$ (air)	131	132	132

Local breakdown of compound will occur at a voltage considerably lower than the puncture voltage.

The curves of Fig. 19 show gradients in paxolin, compound, and air-film, at $x = r_4$ for various values of r_1 and r_2 when $r_3 = 2$ in. and $r_4 = 3$ in.

TABLE 18.

r_1		1·05 in.	1·125 in.	1·225 in.
r_2		1·85 in.	1·59 in.	1·3 in.
Paxolin	Thickness	0·8 in.	0·465 in.	0·975 in.
	Gradient at 100 kV	93	88	81
	Permissible gradient	150	170	210
Compound	Thickness	0·15 in.	0·41 in.	0·7 in.
	Gradient at 100 kV	77	90	110
	Permissible gradient	90	94	96
Porcelain	Thickness	1 in.	1 in.	1 in.
	Gradient at 100 kV	39·2	39·7	39·7
	Permissible gradient	215	215	215
Gradient in air at $x = r_4$		131	132	132

The equation

$$r_1 = \frac{1}{e} r_2^{(1-\epsilon_1/\epsilon_2)} r_3^{(\epsilon_1/\epsilon_2-\epsilon_1/\epsilon_3)} r_4^{(\epsilon_1/\epsilon_3)}$$

gives the relation between r_1 and r_2 for minimum gradient for any given value of r_2. Its range in the above example is between $r_1 = 1$ in. and $r_1 = 1{\cdot}25$ in. The formula must be used with caution as it is quite possible that values of r_1 outside this range (and therefore where the equation cannot be used) may give a smaller value for the gradient in the paxolin than that which is the minimum possible between the limits over which the equation holds.

For example, in the case considered $r_2 = \frac{7}{8}$ in. and $r_1 = \frac{3}{4}$ in. gives a gradient in the paxolin of 80, which is better than that obtained by any combination of r_1 and r_2 set out in Table 18. Completing the calculation for these values of r_1 and r_2 we obtain Table 19.

This design is probably superior to any of those set out in Table 18. One great point in its favour is the comparatively low gradient in the imaginary air film at $x = r_4$. This calculated value of the voltage gradient at $x = r_4$, i.e. in an imaginary film of air between the outer porcelain surface and the earth flange, is important. The value of the stress there has no practical influence on the radial strength of the bushing, but it has considerable influence on the axial flash-over voltages. As the voltage is raised corona appears first about the earth flange and the top cap, and should it appear too soon then flash-over will occur at a correspondingly low voltage. So that, other things being equal, that design is best which gives the lowest value of the gradient at $x = r_4$.

TABLE 19.

r_1		$\frac{3}{4}$ in.
r_2		$\frac{7}{8}$ in.
r_3		2 in.
r_4		3 in.
Paxolin	Thickness	$\frac{1}{8}$ in.
	Gradient at 100 kV	80
	Permissible gradient	200
Compound	Thickness	$1\frac{1}{8}$ in.
	Gradient at 100 kV	98
	Permissible gradient	105
Porcelain	Thickness	1 in.
	Gradient at 100 kV	23·7
	Permissible gradient	215
Gradient in air at $x = r_4$		79

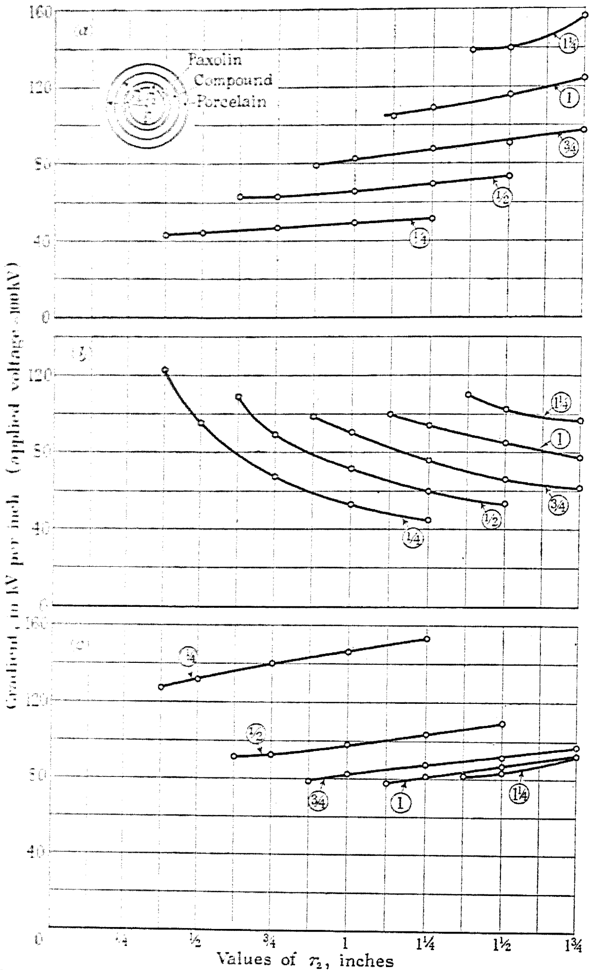

FIG. 19.—Gradients in 3 concentric dielectrics (paxolin, compound, porcelain) for 100kV applied. Figures in circles are values of r_1.

(a) Gradient in imaginary air film near flange at $x = r_4$; where $r_4 = 3$ in. and $r_3 = 2$ in.
(b) Gradient in compound at $x = r_2$.
(c) Gradient in paxolin at $x = r_1$.

All gradients are in kV (R.M.S.) per inch, i.e. volts (R.M.S.) per mil.

Flash-over Characteristics.

Dry flash-over voltage.—The dry flash-over voltage of a bushing for a given set of atmospheric conditions is governed by

(1) The axial clearance from upper metal cap to flange (X in Fig. 20).
(2) The radial dimensions of the bushing.
(3) The type of filling used (e.g. air, oil, compound, etc.).

Over wide limits the axial clearance is the chief controlling feature, but the effect of radial dimensions becomes increasingly important as the length of the bushing increases. For a given set of radial dimensions the flash-over voltage increases with X at first proportionately, but with large values of X an increase of dry flash-over voltage is exceedingly difficult to obtain. The typical curve is shown in Fig. 21.

For large values of X an increase in dry flash-over is best obtained either by increasing the radial dimensions or by using some kind of filling. The control of the radial distribution delays breakdown of the air in the vicinity of the flange, and this in its turn increases the axial flash-over voltage of the bushing.

The curves shown in Fig. 21 embody test results obtained by the author and they may be used for preliminary design purposes for bushings having normal proportions radially and axially. The temperature and barometric pressure are assumed to be 25° C. and 76 cm respectively.

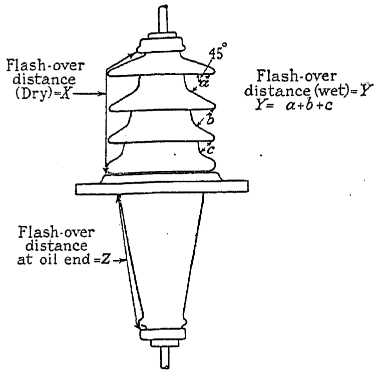
Flash-over distance (Dry)=X
45°
a
b
c
Flash-over distance (wet)=Y
Y= a+b+c
Flash-over distance at oil end=Z

FIG. 20.—Axial distances which control the various flash-over voltages.

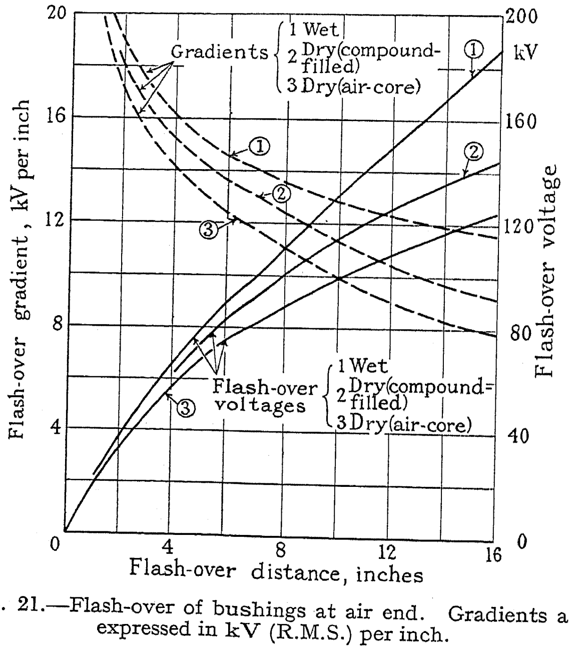

FIG. 21.—Flash-over of bushings at air end. Gradients are expressed in kV (R.M.S.) per inch.

Wet flash-over voltage.—This is affected by atmospheric temperature and pressure in the same way as the dry flash-over voltage, and the same curves may be used for correction. It is also affected by the intensity of rainfall and by the resistivity of the water used for the tests (see Section 2—" Testing of Bushings ").

The chief dimension controlling the wet flash-over is the dry path Y (Fig. 20) provided by the rain sheds when subjected to rainfall, but, as for the dry flash-over, with large values of Y it becomes increasingly difficult to obtain increased wet flash-over voltages from a given set of radial dimensions. Increased radial dimensions and the use of some kind of filling material frequently give the desired flash-over voltage more economically than an increase of axial dimensions. The curves in Fig. 21 may be used for preliminary design purposes with bushings having normal proportions radially and axially. The resistivity of the rain water used is assumed to be 10 000 ohms per cm cube.

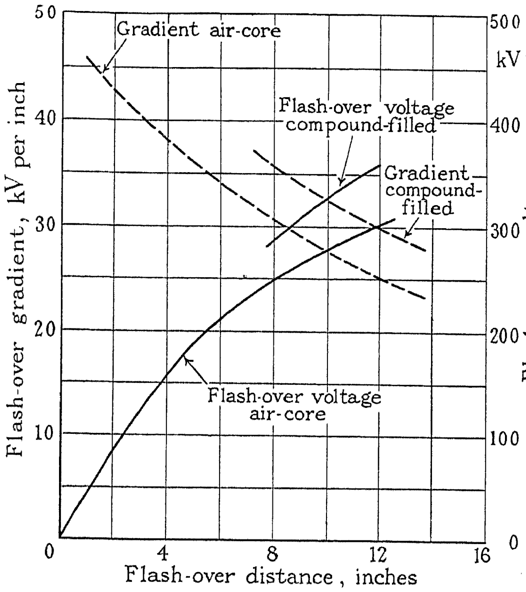

Fig. 22.—Flash-over of bushings at oil end. Gradients are expressed in kV (R.M.S.) per inch.

Flash-over voltage under oil.—Z in Fig. 20 is now the controlling dimension. Any information given under this heading should postulate absolutely clean oil and absolutely clean insulator surface—two conditions difficult (if not altogether impossible) of attainment commercially. The curves shown in Fig. 22 are based on experience obtained under normal operating conditions and so may be used for average commercial conditions.

Somewhat increased flash-over voltage may be obtained by corrugating the surface of the porcelain as shown in Fig. 36.

Heating of Bushings.

Current-carrying capacity of centre conductor.—Currents up to about 2 000 amperes may be carried by a central conductor in the form of a rod. Larger currents necessitate the use of copper of rectangular section.

Table 20 gives current ratings of copper rods of various sizes as used in transformer bushings.

It should be noted that the heating of the centre rod is increased by skin effects and these are appreciable for the larger rods given in Table 20. The loss in the rod is not affected by the presence of the encircling earth flange, and the effective resistance may be calculated by the method given by Prof. Howe* thus:—

$$\frac{\text{Resistance to Alternating Current}}{\text{Resistance to Direct Current}} = \frac{R_f}{R_0}$$

Values of R_f/R_0 for various values of $d\sqrt{f}$ are given in Table 21,

where d = diameter of rod in centimetres, and
f = frequency in cycles per second.

If $d\sqrt{f}$ exceeds 32, $R_f/R_0 = 0{\cdot}038\, d\sqrt{f} + 0{\cdot}25$, e.g. for 2-in. dia. rod and 50 cycles per sec. $d\sqrt{f} = 36$

$$\therefore \frac{R_f}{R_0} = 0{\cdot}038 \times 36 + 0{\cdot}25$$
$$= 1{\cdot}62$$

The loss in the flange is due to hysteresis and eddy-current effects. When heavy currents are being carried this loss raises the temperature of the flange to a noticeable extent. When very heavy currents are being carried the temperature-rise may be excessively great if ordinary cast-iron is used, and some other material such as "No-Mag" must be used. The calculation of this flange loss is a difficult matter.

Fig. 23 shows the position of the thermo-couples used to register the temperature-rise, and Table 22 gives the results of tests for rods and flanges of various sizes. Air-core bushings were used and the whole bushing was in air, the bottom portion not being immersed in hot oil as would be the case in practice.

Table 20.

Current-carrying Capacity of Copper Rods.

Diameter of rod	$\frac{1}{2}$ in.	$\frac{5}{8}$ in.	$\frac{3}{4}$ in.	$\frac{7}{8}$ in.	1 in.	$1\frac{1}{4}$ in.	$1\frac{1}{2}$ in.
Current, amps.	200	350	450	600	750	1 250	1 750

Table 21.

Values of $d\sqrt{f}$ and R_f/R_0 for Rods.

$d\sqrt{f}$	0	4	8	12	16	20	24	28	32
R_f/R_0	1·0	1·0	1·01	1·02	1·04	1·1	1·2	1·33	1·48

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* *Journal I.E.E.*, 1920, vol. 58, p. 152.

Note Regarding Electrical Design of Bushings of the Condenser Type.

These present special design features and such special features have not been dealt with.

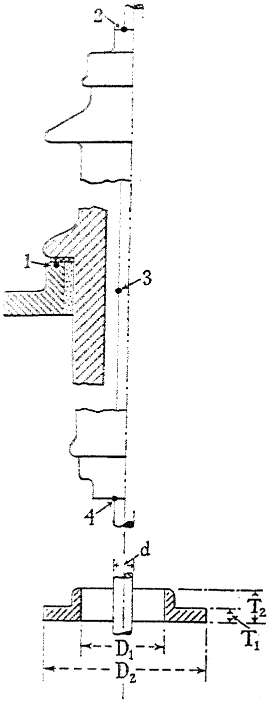


FIG. 23.—Location of thermo-couples as used for determining temperature-rise of conductors and flanges, the dimensions of which are given in Table 22.

1. Flange.
2. Top of rod.
3. Middle of rod.
4. Bottom of rod.

Mechanical Design and Construction of Bushing.

The mechanical design must ensure oil- and weather-tightness while permitting free thermal expansion of metal parts. In addition the design must enable the bushing to withstand whatever stresses may operate on it under working conditions or during erection. The mechanical stresses on transformer bushings are not large, but bushings for switchgear have to withstand the stresses due to the shock of contacts being made and broken. The bottom metal fitting on oil circuit-breaker bushings is for this reason much more robust in construction than the corresponding fitting on a transformer bushing.

The mechanical stresses to which transformer bushings are subject are due chiefly to the normal stresses met with in erection, e.g. the stresses due to spannering action when making connection to the centre conductor; also, after erection, stresses are transmitted from the overhead line, especially if the connection between bushing and line is not sufficiently flexible. Neither of these stresses is very large and they call for no special consideration in design except for bushings of the smallest size. In these small bushings a common form of failure is the breaking of the porcelain neck at section AA in Fig. 24. It has been found that if this section is made not less than $\frac{3}{8}$ in. thick on a mean diameter of 1 in., breakages are uncommon. With bushings for large currents the connections become heavy and risk of damage to the porcelain is increased if ordinary nuts are used to make connection to the centre conductor. A

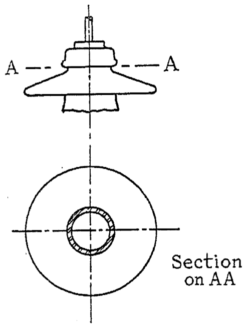


FIG. 24.—Mechanically weakest section of porcelain insulator.

TABLE 22.

Temperature-rise of Rods and Flanges.

Bushing	Material		Current	Dimensions (inches)					Final temperature-rise (deg. C.) at following position in Fig. 23			
	Rod	Flange		d	D_1	D_2	T_1	T_2	1	2	3	4
			amps.									
I	Copper	Cast iron	300	$\frac{5}{8}$	$1\frac{11}{16}$	$4\frac{3}{4}$	$\frac{5}{16}$	$\frac{7}{8}$	22	11·5	12·5	12·5
			400	$\frac{5}{8}$					27·5	15	17·5	17·5
			500	$\frac{5}{8}$					35	21·5	23·5	23·5
II	Copper	Cast iron	500	$\frac{5}{8}$	$2\frac{3}{4}$	$5\frac{3}{4}$	$\frac{1}{2}$	$\frac{7}{8}$	36·5	—	—	—
III	Copper	Cast iron	600	$\frac{5}{8}$	$5\frac{1}{2}$	11	$\frac{5}{8}$	$1\frac{1}{8}$	17·5	—	—	—
IV	Copper	Cast iron	600	$\frac{5}{8}$	$6\frac{3}{8}$	11	$\frac{5}{8}$	$1\frac{3}{4}$	24·5	—	—	—
V	Copper	Cast iron	650	$\frac{7}{8}$	$5\frac{1}{2}$	11	$\frac{5}{8}$	$1\frac{1}{8}$	19	8	12	8
VI*a*	Copper	"No-mag."	1 350	$1\frac{1}{4}$	4	$8\frac{3}{4}$	$\frac{5}{8}$	$2\frac{1}{4}$	0	39	39	37
VI*b*	Copper	Cast iron	1 350	$1\frac{1}{4}$	4	$8\frac{3}{4}$	$\frac{5}{8}$	$2\frac{1}{4}$	Temp.-rise of flange was 100 deg. C. in 25 mins. and still increasing rapidly.			

better method is to use a clamp connector such as that shown in Fig. 25. This is designed to carry a current of 1 750 amperes.

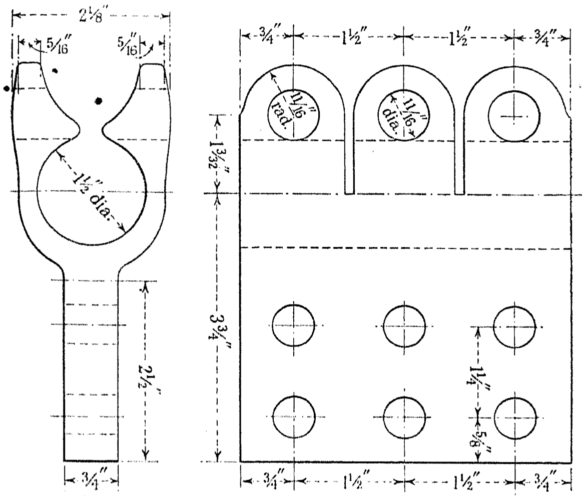


FIG. 25.—Detail of gunmetal terminal to carry 1 750 amperes.

Joints.—The making of oil- and weather-tight joints is a most important item in the mechanical construction of the bushing. The general problem is to attach a metal fitting (e.g. the earth flange) to the porcelain insulator so that the resultant joint is oil- and weather-tight. There are two methods in common use. One method relies entirely on the use of gaskets, while the other method uses gaskets together with some form of reinforcing oil-tight cement such as that made of litharge and glycerine. The gaskets are usually of compressed cork and they should be treated with some composition to assist in securing tightness. Very useful compositions for this purpose are certain glues used in aeroplane manufacture.

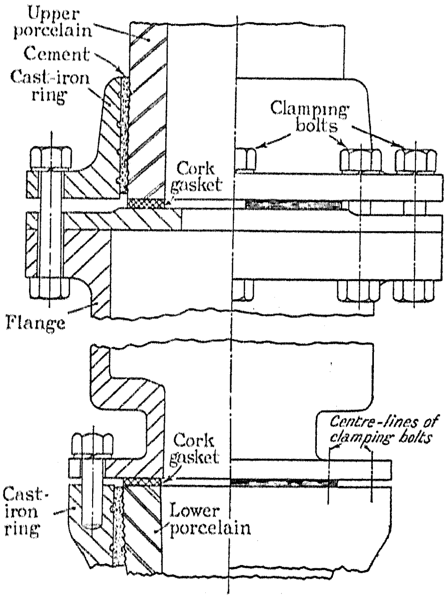


FIG. 26.—Oil-tight joints between porcelain and earth flange. Gasket only.

The "gasket only" method, illustrated in Fig. 26, involves the gripping of the gasket between a ground porcelain surface and a machined metal surface. The two surfaces are pressed together by the action of bolts which seat on to the metal part of the joint and are carried by a metal flange cemented to the porcelain.

The "gasket plus oil-tight cement" method is illustrated in Fig. 27. Here the gasket is pressed tightly against the porcelain surface (which need not be ground) by the metal fitting, which is secured with cement. If oil is to escape it must first get through the cement and then past the joint. This method is cheaper than the "gasket only." The chief argument against its use is that if the joint *does* leak then the repair involves removal of the cement, which is a difficult matter. For large and expensive bushings (say for 66 kV and above) the "gasket only" method is preferable, but for smaller bushings the author has found the "gasket plus cement" method to be quite satisfactory. Various joints can be seen in Fig. 32, which shows a complete oil-filled bushing.

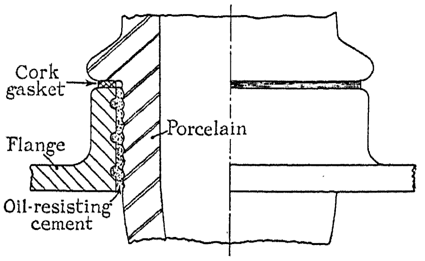


FIG. 27.—Oil-tight joint between porcelain and earth flange. Gasket reinforced with oil-resisting cement.

Connection of transformer winding to bushing.—In the smaller bushings connection is made by simply bringing a connection from the winding to the bottom of the centre conductor. For large transformers it is often convenient to despatch the transformer filled with oil but without bushings, and in such cases the placing of the bushings in position would involve the lowering of the oil-level in the transformer, a procedure which would endanger the dryness of the windings. A method of overcoming this disadvantage and one which is now much used is to take the lead from the winding directly to the top fitting of the bushing. A construction which enables this to be done is shown in Fig. 28. The cable socket or connector shown in the illustration is sweated to the end of a cable (not shown) which is connected to the transformer winding. The cable connector is then pulled up by a wire through the central tube of the bushing and fixed in the manner shown.

(4) TYPES OF BUSHING.

The chief types of outdoor bushing are:—

All-porcelain with air core.

Bushing having porcelain exterior filled with either compound or oil.

Condenser-type bushing made of varnish-paper insulation with layers of aluminium foil and having a protective shroud of porcelain on its exposed surface.

All-porcelain multi-tubular type.

All-porcelain multi-tubular type built up on an elementary condenser-type principle.

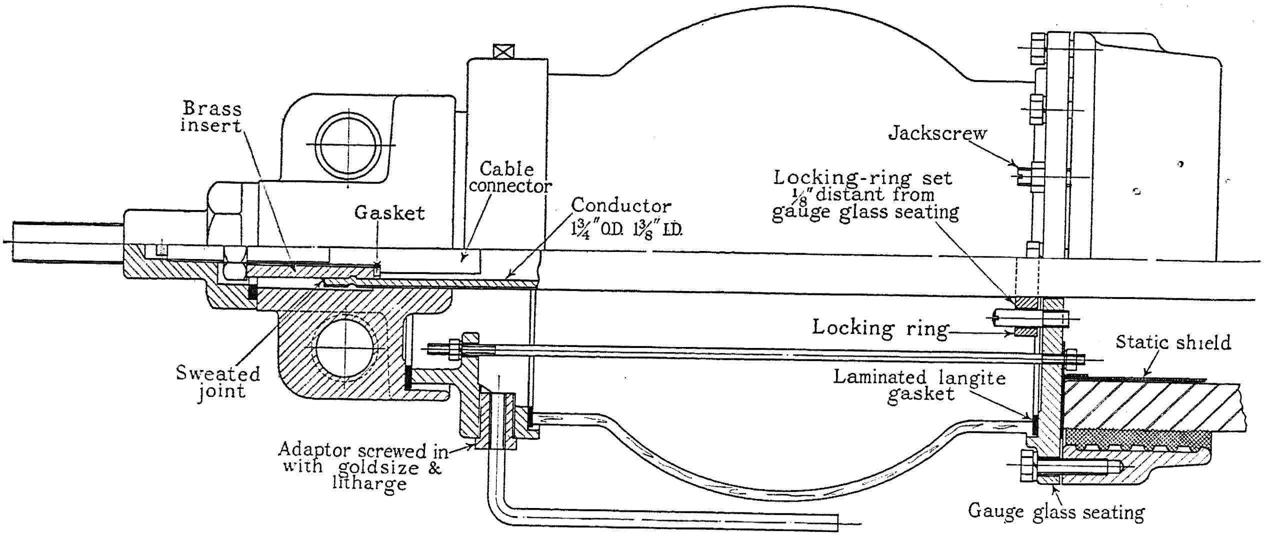


FIG. 28.—Method of connecting transformer winding to top fitting of bushing.

All-porcelain air-core bushings.—These are used to the practical exclusion of all other types up to 22 kV. They are also much used at 33 kV, at which voltage they compete with the condenser and oil- or compound-filled types.

The construction of a typical bushing is shown in Fig. 29. "A" indicates the porcelain and "B" the central rod which carries the transformer current. The flange "C" is cemented to the porcelain with oil-resisting cement as described on page 319. The top cap "D" is also cemented to the porcelain and the central conductor passes through the cap, being secured to it in a manner which ensures its oil-tightness. The bottom cap "E" is attached to the central rod in a manner which allows for the unequal expansion with temperature-rise of the central rod and the porcelain. Table 23 on page 325 gives data concerning a range of air-core bushings.

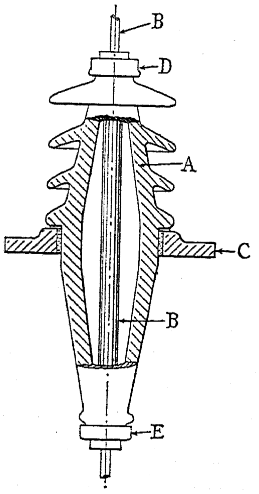


FIG. 29.—Construction of air-core bushing.

Compound-filled bushings.—These are used for working voltages of 33 kV and 44 kV since it is difficult with an air-core bushing to obtain puncture voltages in excess of 200 kV, or flash-over voltage at air-end in excess of approximately 110 kV. Compounds are listed as of the "solid" or of the "semi-fluid" type, but even so-called solid compounds are quite fluid at a temperature of 90° C.—the temperature which is usual in transformer working.

Compound filling may be a difficult matter as the temperature of certain compounds must be about 140–160° C. to enable them to pour with sufficient freedom. If compound at this temperature were poured directly into a cold porcelain container, the porcelain would crack. It is necessary therefore that the porcelain should be raised to a temperature approximating to that of the compound before filling begins. It has been found that if a porcelain shell which has been filled with compound is removed while still hot from the heating chamber, the sudden change of temperature produces stresses in the bushing which may crack the porcelain. These cracks may take days or even weeks before they develop into longitudinal cracks running the whole length of the bushing.

Another very frequent source of trouble with compound-filled bushings is the formation of air pockets in the compound which result in low puncture values on test. The greatest care and knowledge of a certain technique is essential if air pockets are to be absent from compound-filled bushings.

It has, moreover, been found in practice that even if a porcelain shell is successfully filled with compound, serious difficulties may occur under certain conditions owing to compound escaping from the bushing. This trouble was found to occur on test with a batch of compound-filled bushings when a bushing was mounted as in practice (upper portion in air, lower portion immersed in oil) and the temperature of the oil was raised fairly rapidly to 90° C. The trouble was eventually traced to the fact that exceedingly high mechanical pressures were produced inside the bushing under the above conditions. The compound is quite fluid at 90° C., and the high pressure causes the fluid to ooze out at the joints. A series of tests to establish the magnitude of the pressure was carried out, the arrangements being described below.

The completed compound-filled bushing was arranged as in service, the flange resting on the top of a tank while the portion of the bushing below the flange was immersed in oil contained in the tank. This oil could be raised to a temperature of 100° C. at various rates. The upper end of the bushing was surrounded by a container in which was placed water kept at 0° C. A pressure gauge was inserted in the bottom of the bushing to measure any pressure which might appear there. The results of typical tests are shown in Fig. 30.

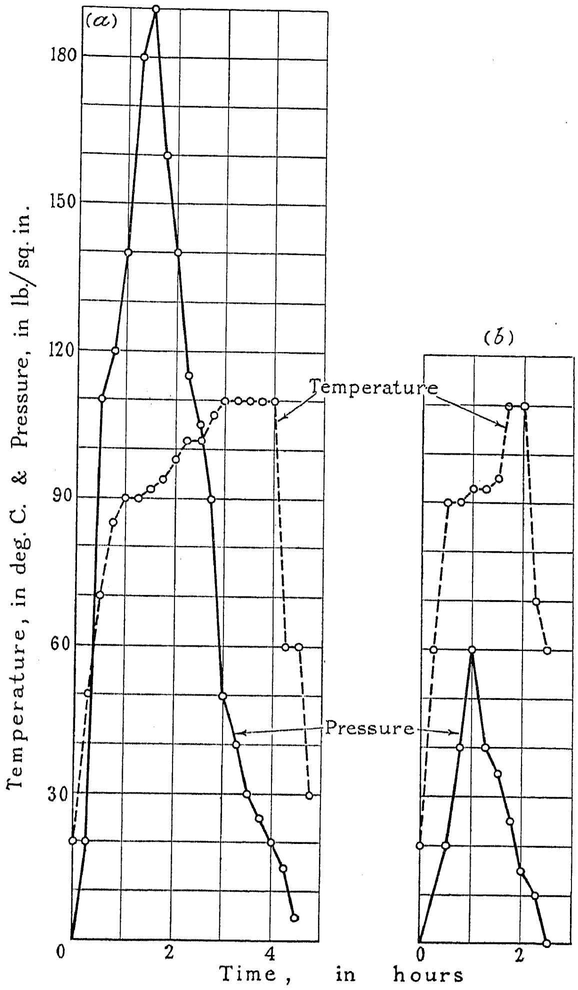


Fig. 30.—Variation of pressure with temperature of compound-filled bushing.

(a) Variation of pressure inside bushing with temperature at oil end. Air end maintained at 0° C.
(b) As (a), but temperature of air end maintained at 10° C.

It appears to be clear from the figures that what happens during the test is somewhat as follows:—The compound contained in the portion of the bushing immersed in the hot oil expands, and the expansion is resisted by the solid mass of compound above it. This gives rise to high pressures in the bottom of the bushing. With increasing temperature the pressure rises to a maximum and then falls to zero, presumably because the heat has travelled slowly through the mass of compound, giving to it a certain fluidity which eventually permits of free expansion.

The compound used was a "solid" compound having the following physical characteristics:—

Melting-point by ball-and-ring method	65° C.
Pouring temperature	175° C.
Coefficient of expansion	0·00063 per deg. C.

The test is admittedly very severe, probably much more severe than will occur under actual operating conditions. If, however, one assumes a transformer tank in service covered with snow and the transformer then switched on to its load the conditions will approximate somewhat closely to those holding during the tests just described, and mechanical pressures of disturbing magnitude may be generated in the bushing if compound filling of this nature is used. Instead of such a solid compound, one having a semi-fluid nature should be used.

A compound-filled bushing gives higher flash-over and puncture figures than the same bushing with air core, e.g. a bushing with air core gave the following test-results:—Flash-over voltage (dry) 105 kV; puncture voltage 150 kV. When filled with compound and tested at a temperature of 67° F. the flash-over voltage (dry) was increased to 120 kV and the puncture voltage to 210 kV. Solid insulation wrapped round the centre conductor is frequently used as reinforcement in compound-filled bushings. A compound-filled bushing with paxolin (varnish-paper) insulation round the centre conductor is shown in Fig. 31. Its electrical characteristics are: Flash-over voltage (dry) 110 kV; flash-over voltage (wet) 72 kV; flash-over voltage at oil end 150 kV. Table 24 on page 325 gives data concerning compound-filled bushings.

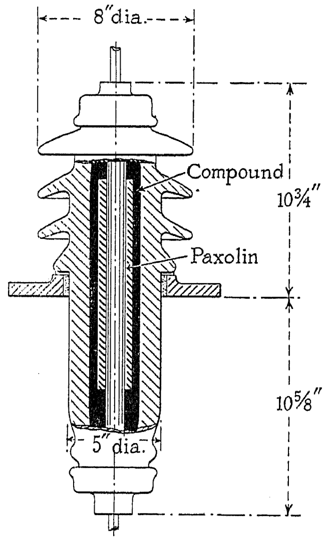


Fig. 31.—Construction of compound-filled bushing with paxolin round centre conductor.

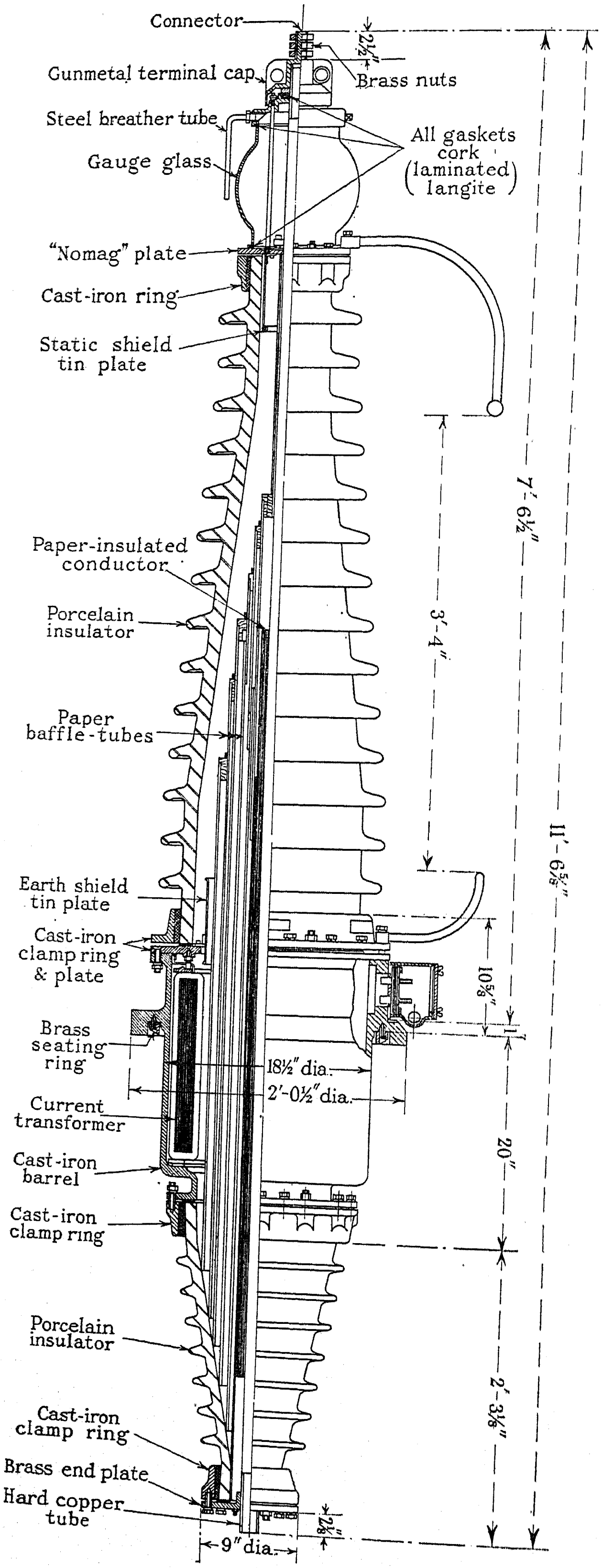


FIG. 32.—Oil-filled bushing for oil circuit-breaker. Working voltage 132 kV.

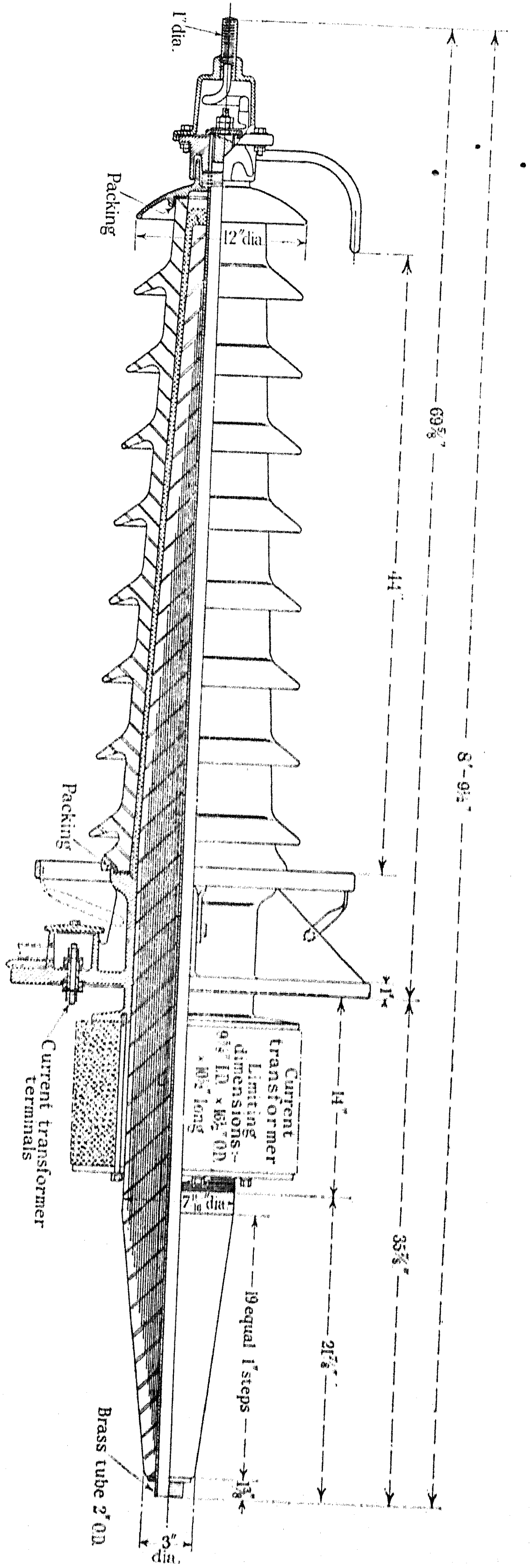


FIG. 33.—Condenser-type bushing for transformer. Working voltage 132 kV.

Oil-filled bushings.—These are suitable for voltages of from 33 kV up to the highest voltages used. The oil-filling of a porcelain shell gives to the resultant bushing practically the same electrical characteristics as if it were compound-filled. The flash-over voltage at the air end is usually somewhat higher with the oil filling, and the puncture voltage a little lower.

Oil is much more expensive than compound and it is customary to demand that oil-filled bushings shall incorporate an expansion chamber with gauge glass to indicate the level of the oil in the bushing. This provision adds still further to the expense. On the other hand, it is much easier to fill the porcelain with oil than with compound. It can be done at ordinary air temperature and air pockets cannot form. The difficulty of providing satisfactory joints is not much greater than for compound (since compound is fluid at working temperature), and there is no likelihood of considerable mechanical pressures forming inside the bushing.

The inside of oil-filled bushings may either be hermetically sealed from the outside atmosphere or arranged to be in direct communication with it. If sealed, then a pressure will be generated in the bushing when the oil expands and this pressure will be exerted on various joints, with consequent increased risk of leakage. To avoid this, many oil-filled bushings have fitted at the top of the reservoir an open tube bent downwards to prevent direct entry of rain water. This maintains atmospheric pressure inside the bushing, but there is risk of the insulating quality of the oil being impaired by the absorption of moisture from the atmosphere.

In oil-filled bushings it is customary to reinforce the oil with solid insulation. For voltages below 66 kV this solid insulation is usually placed immediately adjacent to the centre conductor. For higher voltages it forms a system of concentric tubes arranged as baffles which divide the oil into a number of thin ducts. The oil, now being in thin layers, is utilized to the best advantage, streamers are prevented from lining up in the oil, and there is a considerable backing of solid insulation. Varnish paper is the solid insulation usually employed, but it now has a rival in porcelain. The varnish-paper insulation can be wound directly on to the centre conductor and this gave it a great advantage over porcelain until recently, when an alloy was introduced which can be used to cement a porcelain tube directly on to the centre conductor. When used as tubes the varnish paper has the advantage that the long thin tubes required can be more easily made of this material than of porcelain. On the other hand, porcelain has the advantage that its electric strength is unaffected by temperatures up to 90° C., whereas varnish-paper insulations show a considerable reduction in electric strength as the temperature is raised. Also the surface of a varnish-paper insulation is much more liable to damage by minor corona discharges which may occur at its surface.

Fig. 32 shows an oil-filled bushing for a 132-kV oil circuit-breaker. Data concerning oil-filled bushings are given in Tables 25 and 26 on page 325. Table 25 refers to bushings using varnish-paper insulation as solid reinforcement, while for the bushings of Table 26 porcelain is used.

Condenser-type bushings.—These are used over practically the same voltage range as oil-filled bushings. Fig. 33 shows a 132-kV condenser-type bushing as used on transformers for the British "grid." Table 27 (page 326) gives particulars of a range of such bushings. The condenser-type bushing has several very obvious advantages when compared with the oil-filled bushing. For the same electrical characteristics the condenser type is smaller and lighter, and it is much easier to make oil- and weather-tight. When current transformers are incorporated the smaller diameter makes them cheaper and more accurate than the larger ones used with oil-filled bushings. An obvious disadvantage of the condenser type is that it is more expensive than the oil-filled type. Other advantages and disadvantages are less obvious and round these much controversy has centred. Undoubtedly many users have had trouble with bushings of the condenser type, while trouble with the oil-filled type is rare. As against this, a very large number of condenser-type bushings have given perfect service. The condenser-type bushing is much more complicated than the oil-filled type. It must be made by specialist manufacturers, every stage of its construction must be carefully supervised, and the complete bushing must be rigorously tested. The testing involves expensive apparatus and skilled operators. The position is aggravated by the fact that the material of which the bushing is made—paper—may deteriorate with time owing to various actions.

Oil-filled bushings are much less exacting in the technique demanded for their construction. They can be made in an ordinary workshop without any very special precautions being taken during their manufacture, and their testing is simple. For these reasons they commend themselves to switchgear or transformer manufacturers who prefer to make their own bushings. A further advantage of the oil-filled bushing is that the materials employed in its construction, viz. porcelain and oil, do not deteriorate with time.

In the opinion of the author, condenser bushings can be obtained which will give no more trouble than any other type, but if, for reasons of cheapness or for any other considerations, such bushings are bought from firms who are inexperienced or careless in their manufacture, then trouble is inevitable.

All-porcelain multi-tubular type.—The great merit of bushings of this type is their simplicity, which makes for reliability in service. Their disadvantages are that they are heavy and costly. They consist essentially of a number of porcelain tubes arranged in concentric formation, a typical bushing being shown in Fig. 34. Its characteristics are given in Table 28 (see page 326).

This type of bushing is free from the disadvantages associated with bushings having "paper base" insulation, and it is also free from the disadvantage of oil-filled bushings that if a defective joint allows the oil to escape then the electric strength of the bushing is seriously impaired. These advantages are maintained and the disadvantages of bulk and cost are to a considerable extent reduced in the last type of bushing which will now be described.

All-porcelain bushings incorporating condenser principle.—These bushings are again essentially a number of porcelain tubes arranged in concentric formation. It is difficult to make porcelain tubes of the length and diameter necessary for these bushings, which will fit over one another without providing fairly large tolerances on the tubes. This renders unavoidable the existence of spaces at least ¼ in. wide between tubes.

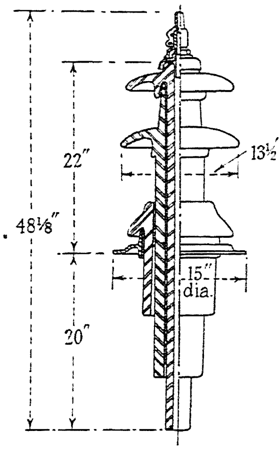


FIG. 34.—All-porcelain multi-tubular type of bushing.

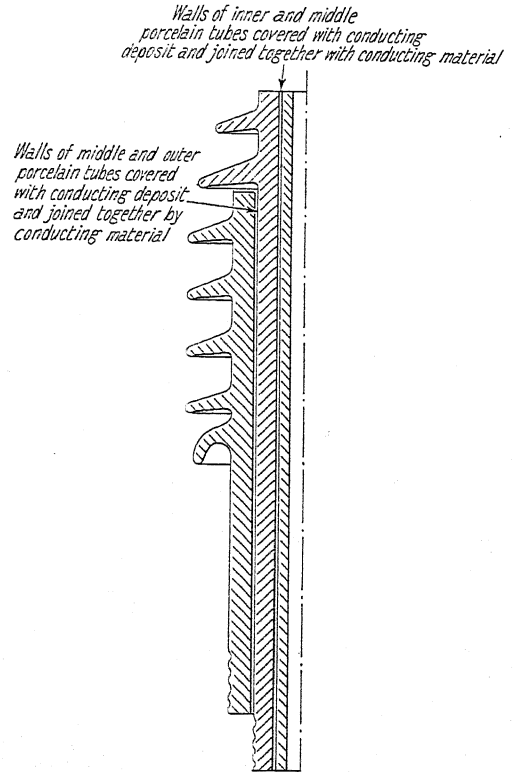

Walls of inner and middle porcelain tubes covered with conducting deposit and joined together with conducting material
Walls of middle and outer porcelain tubes covered with conducting deposit and joined together by conducting material

FIG. 35.—Porcelain for 66-kV all-porcelain bushing.

In the type of bushing now being described the inner and outer surface of each tube are coated with a conducting layer which is either of graphite or metal sprayed on to the surface of the porcelain. This spraying of metal on to porcelain is becoming well established on commercial lines and the metal surface is quite permanent.

The porcelain tubes are assembled one over the other with the unavoidable space separating them. The inner and outer conducting layers on two adjacent tubes are joined by conducting material. The outer coating on one tube and the inner coating on the next are thus in electrical contact with each other. The remainder of the space between the tubes is filled with insulating compound which serves no insulating purpose but definitely fills the space to the exclusion of any undesirable material.

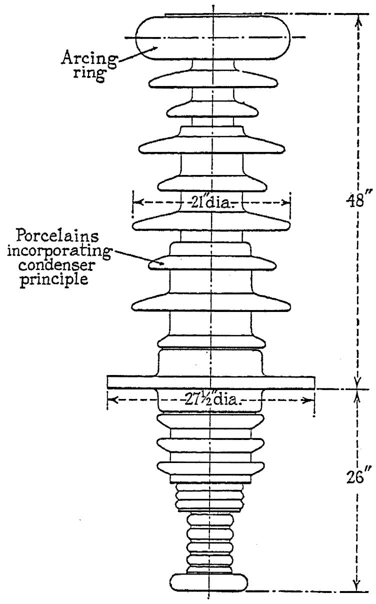


FIG. 36.—All-porcelain bushing incorporating condenser-type construction, for 132-kV working voltage.

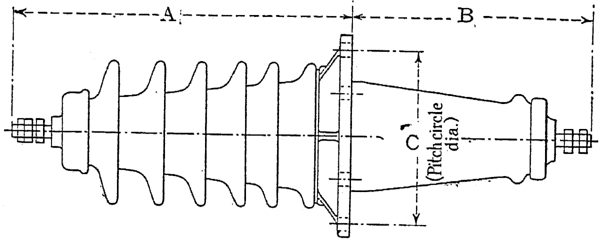


FIG. 37.

The diameters and lengths of the conducting layers are arranged on the condenser principle. In effect a solid porcelain wall is obtained between centre conductor and flange, but the electrostatic stress distribution is controlled and improved by the use of the conducting layers.

A typical porcelain for a bushing of this kind is shown in Fig. 35, and the electrical characteristics of the 132-kV bushing of this type (see Fig. 36) are: Flash-over voltage (dry) = 480 kV; flash-over voltage (wet) = 350 kV. Table 29 (see page 326) gives particulars of a range of these bushings.

TABLE 23.

Air-Core Bushings.

Design number	Flash-over voltage			Dimension (see Fig. 37)			Weight
	Wet	Dry	Under oil or puncture	A	B	C	
	kV	kV	kV	in.	in.	in.	lb.
1	20	35	60	$5\frac{7}{8}$	4	$3\frac{3}{8}$	$3\frac{1}{2}$
2	25	45	75	$7\frac{1}{8}$	$5\frac{1}{2}$	$3\frac{7}{8}$	$4\frac{1}{4}$
3	30	50	87	$7\frac{1}{4}$	$7\frac{3}{16}$	$4\frac{5}{8}$	8
4	40	62	110	$8\frac{1}{2}$	$7\frac{5}{16}$	$4\frac{5}{8}$	10
5	50	82	120	$10\frac{3}{8}$	$8\frac{1}{8}$	6	$15\frac{3}{4}$
6	62	95	150	$12\frac{5}{8}$	$12\frac{3}{8}$	$9\frac{1}{2}$	36
7	90	110	180	18	$13\frac{1}{8}$	$9\frac{1}{2}$	72

TABLE 24.

Compound-filled Bushings.

Design number	Flash-over voltage			Dimension (see Fig. 37)			Weight
	Wet	Dry	Under oil or puncture	A	B	C	
	kV	kV	kV	in.	in.	in.	lb.
1	72	110	180	$12\frac{7}{8}$	$14\frac{11}{16}$	$9\frac{1}{2}$	51
2	115	135	220	$18\frac{3}{8}$	$14\frac{11}{16}$	$9\frac{1}{2}$	94

TABLE 25.

Oil-filled Bushings. 1st Design (Solid Reinforcement of Varnish-Paper Tubes).

Design number	Flash-over voltage			Dimension (see Fig. 37)			Weight
	Wet	Dry	Under oil or puncture	A	B	C	
	kV	kV	kV	in.	in.	in.	lb.
1	110	140	185	$29\frac{1}{4}$	$12\frac{1}{8}$	$7\frac{3}{4}$	115
2	200	250	350	$50\frac{3}{16}$	$18\frac{7}{8}$	$12\frac{1}{2}$	385
3	280	375	550	80	$27\frac{1}{2}$	$22\frac{3}{4}$	1 000

TABLE 26.

Oil-filled Bushings. 2nd Design (Solid Reinforcement of Porcelain Tubes).

Design number	Flash-over voltage			Dimension (see Fig. 37)			Weight
	Wet	Dry	Under oil or puncture	A	B	C	
	kV	kV		in.	in.	in.	lb.
1	150	230	Not stated	$42\frac{7}{8}$	$18\frac{5}{8}$	20	280
2	180	260		$48\frac{1}{2}$	$18\frac{5}{8}$	$16\frac{3}{4}$	295
3	210	275		$51\frac{7}{8}$	$27\frac{5}{8}$	20	430
4	240	340		$58\frac{1}{8}$	36	24	659
5	320	420		72	$35\frac{3}{4}$	24	930
6	420	620		$88\frac{7}{8}$	$36\frac{1}{8}$	28	1 500

TABLE 27.

Condenser-Type Bushings.

Design number	Flash-over voltage			Dimension			Weight
	Wet	Dry	Under oil or puncture	A	B	C	
	kV	kV		in.	in.	in.	lb.
1	60	95	Not stated	18	$10\frac{1}{2}$	6	42
2	85	125		20	12	8	52
3	95	140		$24\frac{1}{2}$	$13\frac{3}{4}$	8	68
4	130	190		$34\frac{5}{8}$	$16\frac{3}{8}$	$9\frac{3}{4}$	84
5	175	240		38	$15\frac{3}{4}$	8	112
6	195	285		$51\frac{1}{4}$	$21\frac{3}{4}$	13	192
7	250	350		$57\frac{1}{4}$	$23\frac{3}{4}$	$13\frac{3}{8}$	328
8	320	400		$69\frac{5}{8}$	$35\frac{7}{8}$	$22\frac{3}{4}$	468

TABLE 28.

All-Porcelain Multi-tubular Type.

Design number	Flash-over voltage			Dimension			Weight
	Wet	Dry	Under oil or puncture	A	B	C	
	kV	kV		in.	in.	in.	lb.
1	32	76	Not stated	15	10	$6\frac{3}{8}$	21
2	50	90		$18\frac{1}{2}$	10	$7\frac{3}{4}$	28
3	70	110		$21\frac{1}{8}$	13	$8\frac{3}{4}$	48
4	90	120		$21\frac{1}{8}$	13	$10\frac{3}{4}$	73
5	90	125		$21\frac{1}{8}$	17	$13\frac{3}{4}$	103
6	116	155		$24\frac{1}{8}$	20	$10\frac{3}{4}$	97
7	120	165		$24\frac{1}{8}$	20	$13\frac{3}{4}$	136
8	135	175		$28\frac{1}{8}$	20	$13\frac{3}{4}$	141
9	140	190		$36\frac{1}{8}$	30	$16\frac{3}{4}$	268
10	160	200		$33\frac{5}{8}$	$32\frac{1}{2}$	$19\frac{3}{4}$	348

TABLE 29.

All-Porcelain, Multi-tubular, with Condenser Construction.

Design number	Flash-over voltage			Dimension			Weight
	Wet	Dry	Under oil or puncture	A	B	C	
	kV	kV	kV	in.	in.	in.	lb.
1	160	195	240	$26\frac{5}{8}$	$15\frac{1}{8}$	10	130
2	185	230	300	34	21	$11\frac{1}{2}$	240
3	240	295	410	$38\frac{1}{2}$	25	$14\frac{5}{8}$	424
4	288	340	435	42	34	15	600
5	415	465	570	$52\frac{1}{4}$	$41\frac{3}{4}$	19	1 125
6	575	640	800	86	46	$31\frac{5}{8}$	3 130

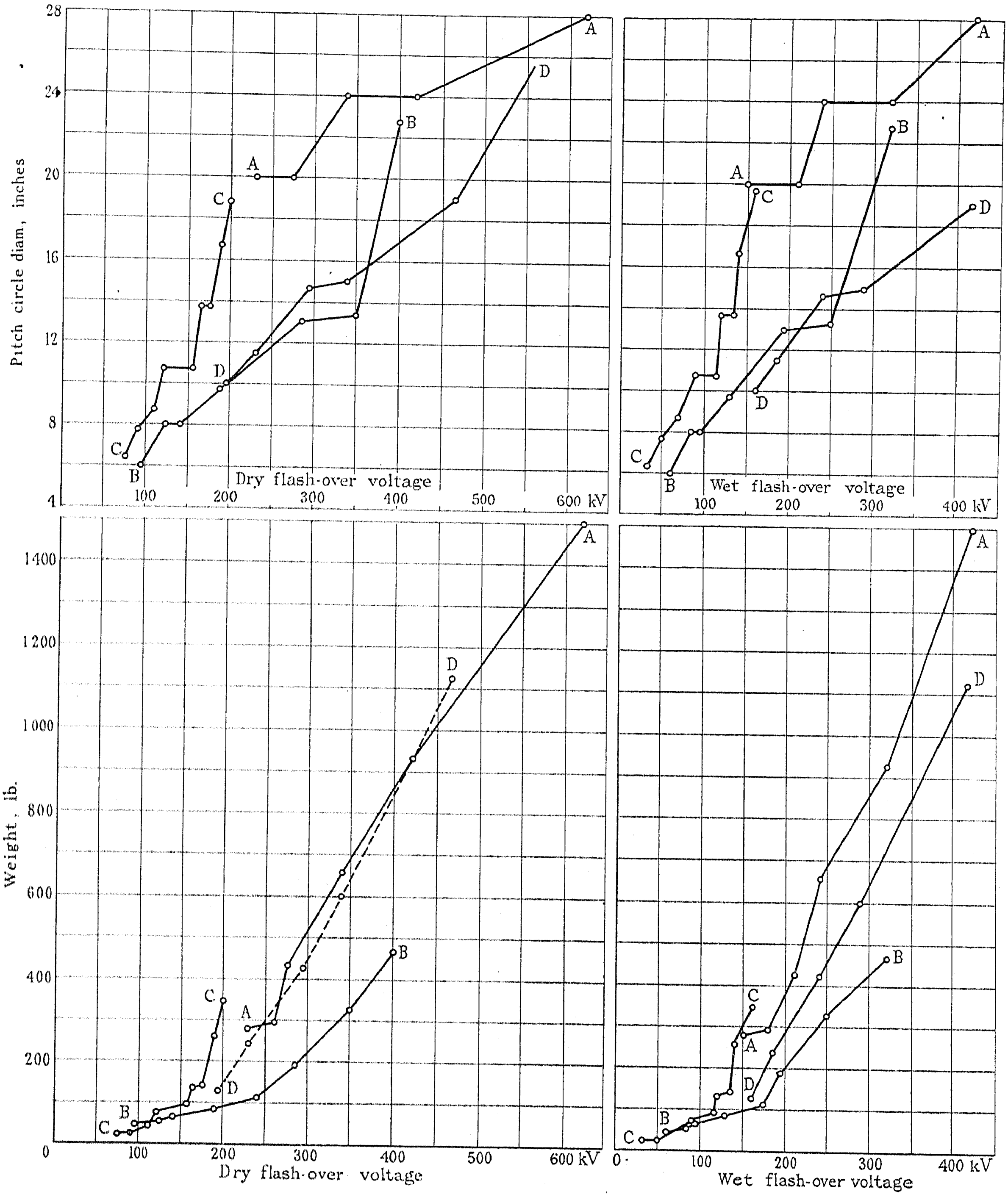


FIG. 38.—Comparison of various types of bushings.

Curves A.—Particulars from Table 26, page 325 (Oil-filled, porcelain reinforced).
Curves B.—Particulars from Table 27, page 326 (Condenser).
Curves C.—Particulars from Table 28, page 326 (All-porcelain multi-tubular).
Curves D.—Particulars from Table 29, page 326 (All-porcelain, condenser construction).

Dimensions and flash-over characteristics of the various types of bushings.—The leading characteristic is taken to be the wet flash-over voltage, and particulars are given with reference to it. In most cases the weight is for a $\frac{5}{8}$-in. dia. central conductor. Dimensions A, B, C, are shown in Fig. 37.

Fig. 38 shows how the weight and the pitch circle diameter vary for bushings of different types. It is plotted from the figures given in Tables 26, 27, 28, and 29.

Current Transformers; Capacitance Coupling.

Current transformers.—Most large transformers include a current transformer as part of the bushing. The primary is the through conductor of the bushing and the secondary is arranged round it. Figs. 32 and 33 show current transformers included in the construction of the bushings; these are used in connection with metering equipment.

A recent development uses an internal current transformer with a wound primary consisting of multiple windings. These windings may be connected in various ways by means of links usually located at the top of the bushing, so as to give a high degree of current-transformer accuracy over a wide range of primary current.

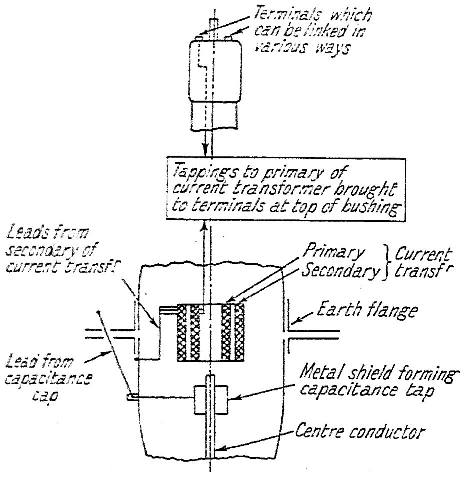

Terminals which can be linked in various ways
Tappings to primary of current transformer brought to terminals at top of bushing
Leads from secondary of current transf^r
Primary
Secondary
Current transf^r
Earth flange
Lead from capacitance tap
Metal shield forming capacitance tap
Centre conductor

FIG. 39.—Diagrammatic representation of bushing with wound-primary current transformer and capacitance tap.

Capacitance coupling.—Another recent development has been the introduction into oil-filled bushings of an internal metal sleeve from which connection is made to external apparatus. The sleeve constitutes a potential tapping or capacitance coupling. It acquires a voltage which is a constant fraction of the line voltage, and this coupling voltage can be used instead of employing a potential transformer. The capacitance coupling is very useful at the higher voltages for giving an accurate measure of the high-tension voltages, for metering, for synchronizing purposes, for carrier-current communication, and for relay operation. When used for relay operation considerable saving in energy consumption is effected as compared with alternative methods, and the absence of potential transformers raises the standard of insulation of the system. The coupling voltage is usually passed through a step-down transformer and then to the switchboard.

Fig. 39 shows diagrammatically a bushing equipped with internal wound-primary transformer and capacitance coupling, and Fig. 40 shows a 220-kV bushing similarly equipped. The connection diagram is given in Fig. **41.**

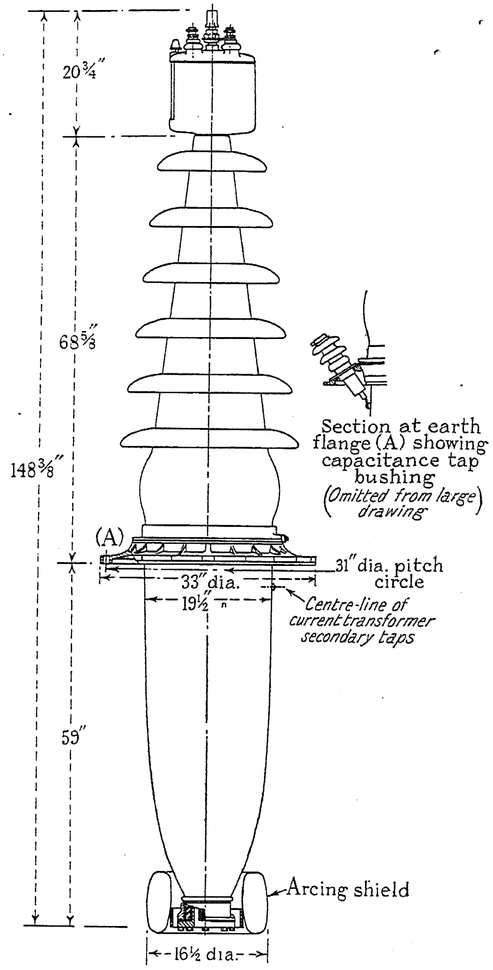

20¾″
68⅜″
148⅜″
59″
(A)
33″dia.
19½″
31″dia. pitch circle
Centre-line of current transformer secondary taps
Section at earth flange (A) showing capacitance tap bushing (Omitted from large drawing)
Arcing shield
16½ dia.

FIG. 40.—220-kV oil circuit-breaker bushing with wound-primary current transformer and capacitance tap.

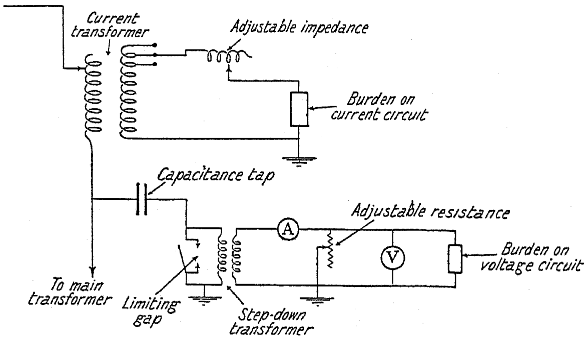


FIG. 41.—Diagram of connections for bushing with wound-primary current transformer and capacitance tap.

Acknowledgments.—This paper was written in the Electrical Engineering Department of East London College. The author wishes to express his thanks to the following firms for information concerning bushings of their

manufacture:—Messrs. Micanite and Insulators Co., Ltd.; Messrs. British Thomson-Houston Co., Ltd.; Messrs. Rosenthal and Co., of Selb, Bavaria; and Messrs. Ohio Brass Co., of Mansfield, U.S.A. His especial thanks are due to Messrs. Electric Transmission, Ltd., and to Messrs. Taylor, Tunnicliff, Ltd., for permission to publish information obtained while testing bushings made by these firms.

APPENDIX I.

RELATION OF WET TO DRY FLASH-OVER VOLTAGE IN BUSHING WHERE THESE ARE MADE AS NEARLY EQUAL AS POSSIBLE.

Fig. 42 shows stages in the development of the insulator contour. Referring to Fig. 43,

$$\tan\theta = \frac{\sqrt{2}-1}{1} = 0{\cdot}414,$$

$$\therefore\ \theta = 22^\circ.$$

$$B = \sqrt{[P^2 + (0{\cdot}414\,P)^2]}$$
$$= P \times 1{\cdot}08$$

The slope of the upper shed need not, of course, be the same as that of the other sheds. If it is made flat, then $B = P$. This is never done, as the shed must be given some slope to allow of the rapid escape of rain water. The slope should not be too great, as this will necessitate an increase in the length of the bushing. When the contour of the insulator is sloping, then, as seen from Fig. 44, the slope of the upper shed if made equal to that of the others is less than θ. So that by taking $\theta = 22^\circ$ the dimension B will in general be on the large side.

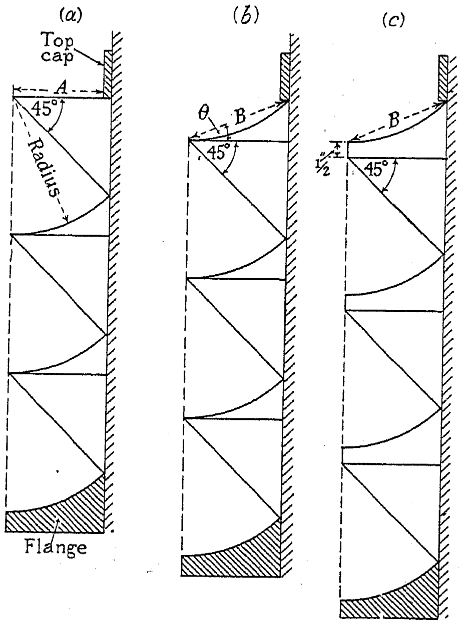


FIG. 42.

(a) Development of shedded contour of insulator surface.
(b) Further development making slope of top shed same as that of other sheds.
(c) Further development allowing ½ in. thickness of shed.

In (a) Flash-over distance (dry) is greater than flash-over distance (wet) by amount A.

In (b) Flash-over distance (dry) is greater than flash-over distance (wet) by amount B.

In (c) Flash-over distance (dry) is greater than flash-over distance (wet) by amount $B + \frac{1}{2}n$, where n = number of sheds.

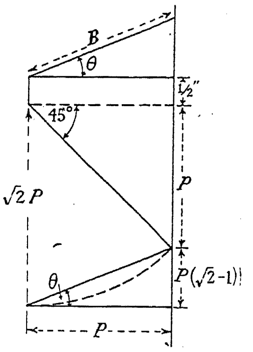


FIG. 43.—Wet and dry flash-over distance in typical section.

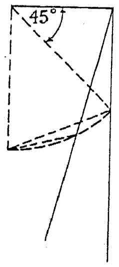


FIG. 44.—Effect of sloping contour of insulator.

Wet flash-over distance $= n\sqrt{(2)}P$.
Hence dry flash-over distance $= n\sqrt{(2)}P + \frac{1}{2}n + 1{\cdot}08P$

$$\therefore\ \frac{\text{Flash-over distance (dry)}}{\text{Flash-over distance (wet)}} = \frac{n\sqrt{(2)}P + \frac{1}{2}n + 1{\cdot}08P}{n\sqrt{(2)}P}$$
$$= 1 + \frac{1}{2\sqrt{(2)}P} + \frac{1{\cdot}08}{n\sqrt{2}}$$
$$= 1 + \frac{n}{2W} + \frac{1{\cdot}08}{n\sqrt{2}}$$

where W = wet flash-over distance $= n\sqrt{(2)}P$, i.e. $\sqrt{(2)}P = W/n$.

If $a = \dfrac{n}{2W} + \dfrac{1{\cdot}08}{n\sqrt{2}}$, then:—

When $n = 1,\ a = \dfrac{1}{2W} + 0{\cdot}77.$

$n = 2,\ a = \dfrac{2}{2W} + 0{\cdot}385.$

$n = 3,\ a = \dfrac{3}{2W} + 0{\cdot}26.$

$n = 4,\ a = \dfrac{4}{2W} + 0{\cdot}19.$

$n = 5,\ a = \dfrac{5}{2W} + 0{\cdot}15.$

$n = 10,\ a = \dfrac{10}{2W} + 0{\cdot}08.$

TABLE 30.

W (inches)						
1	n = **1**	2	3	4	5	10
	a = **1·27**	1·385	1·76	2·19	2·65	5·08
2	n = **1**	**2**	3	4	5	10
	a = **1·02**	**0·88**	1·01	1·19	1·4	2·58
3	n = **1**	**2**	**3**	**4**	5	10
	a = **0·93**	**0·71**	**0·76**	**0·86**	0·98	1·74
4	n = *1*	**2**	**3**	**4**	**5**	10
	a = *0·89*	**0·63**	**0·635**	**0·69**	**0·77**	1·33
5	n = *1*	**2**	**3**	**4**	**5**	10
	a = *0·87*	**0·58**	**0·56**	**0·59**	**0·65**	1·08
10	n = *1*	*2*	*3*	**4**	**5**	**10**
	a = *0·82*	*0·45*	*0·41*	**0·39**	**0·40**	**0·58**
15	n = *1*	*2*	*3*	*4*	*5*	**10**
	a = *0·80*	*0·48*	*0·36*	*0·32*	*0·32*	**0·41**
20	n = *1*	*2*	*3*	*4*	*5*	**10**
	a = *0·80*	*0·43*	*0·336*	*0·29*	*0·28*	**0·33**
25	n = *1*	*2*	*3*	*4*	*5*	**10**
	a = *0·79*	*0·42*	*0·32*	*0·27*	*0·25*	**0·28**
30	n = *1*	*2*	*3*	*4*	*5*	**10**
	a = *0·79*	*0·42*	*0·31*	*0·26*	*0·25*	**0·24**

Calculating a for various values of W and n, the results obtained are given in Table 30.

Sheds having a projection of less than $\frac{1}{2}$ in. or more than 2 in. are rarely economical designs.

If $P = \frac{1}{2}$ in., then the minimum value for W when

$n = 1$ is 0·71 in.
$n = 2$ is 1·41 in.
$n = 5$ is 3·53 in.
$n = 10$ is 7·07 in.

The figures in ordinary type in cols. 3, 4, 5, 6, and 7, in Table 30 indicate eliminations consequent on this condition.

If $P = 2$ in., then the maximum value for W when

$n = 1$ is 2·83 in.
$n = 2$ is 5·66 in.
$n = 5$ is 14·14 in.
$n = 10$ is 28·28 in.

The figures in italics in cols. 2, 3, 4, 5, and 6, indicate eliminations consequent on this condition. An examination of the remaining values (shown in heavy type) in the table shows that—

When $W = 1$, dry flash-over distance is 2·27.
$W = 2$, dry flash-over distance may vary between 4·04 and 3·76.
$W = 3$, dry flash-over distance may vary between 5·79 and 5·58.
$W = 4$, dry flash-over distance may vary between 6·52 and 7·08.
$W = 5$, dry flash-over distance may vary between 7·9 and 8·25.
$W = 10$, dry flash-over distance may vary between 13·9 and 15·8.
$W = 15$, dry flash-over distance is 21·2.
When $W = 20$, dry flash-over distance is 26·6.
$W = 25$, dry flash-over distance is 32.
$W = 30$, dry flash-over distance is 37·2.

Thus for any given flash-over distance (and therefore flash-over voltage) under wet conditions, the corresponding dry flash-over distance (and therefore dry flash-over voltage) can be fixed within narrow limits.

Corresponding values of wet (W) and dry (D) flash-over distances are plotted in Fig. 45A. Taking voltage gradients for the various distances from Fig. 21, and plotting corresponding values of wet and dry flash-over voltages, Fig. 45B is obtained. The straight-line relationship between these flash-over figures is:—

Dry flash-over (kV) = 0·94 wet flash-over (kV) + 20.

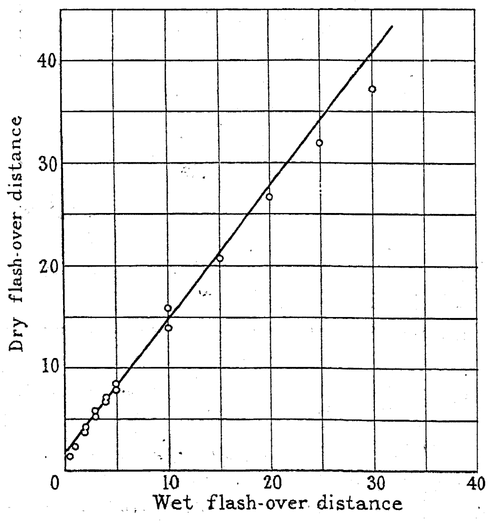


FIG. 45A.—Relation between wet and dry flash-over distances (inches).

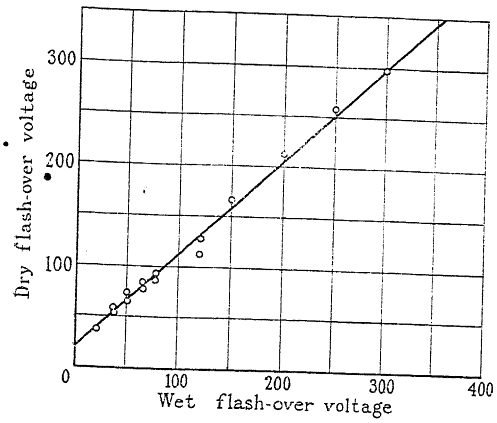


FIG. 45B.—Relation between wet and dry flash-over voltages (kV).

APPENDIX II.

AIR-CORE PORCELAIN BUSHINGS.

Value of r_1 which Gives Maximum Voltage before Corona Appears on Inner Conductor (see Fig. 16).

Corona voltage

$$V = gr_1\left\{\log_e \frac{r_2}{r_1} + \frac{1}{5}\log_e \frac{r_3}{r_2}\right\}$$

The permissible gradient in air is

$$g_{max.} = 55\cdot 5\left[1 + \frac{0\cdot 193}{\sqrt{r}}\right] \text{ kV (R.M.S.) per inch}$$

(see page 311)

$$= 55\cdot 5 + \frac{10\cdot 7}{\sqrt{r}}$$
$$= A + B/\sqrt{r}$$

where $A = 55\cdot 5$ and $B = 10\cdot 7$.

Corona voltage (R.M.S.)

$$V = \left(A + \frac{B}{\sqrt{r_1}}\right) r_1\left\{\log_e r_2 - \log_e r_1 + \tfrac{1}{5}(\log_e r_3 - \log_e r_2)\right\}$$
$$= \left(A + \frac{B}{\sqrt{r_1}}\right) r_1\left\{\tfrac{4}{5}\log_e r_2 - \log_e r_1 + \tfrac{1}{5}\log_e r_3\right\}$$
$$= \left(A + \frac{B}{\sqrt{r_1}}\right) r_1\left\{C - \log_e r_1\right\}$$

where $C = \frac{4}{5}\log_e r_2 + \frac{1}{5}\log_e r_3$

$$= (Ar_1 + B\sqrt{r_1})(C - \log_e r_1)$$
$$= ACr_1 + BC\sqrt{r_1} - Ar_1\log_e r_1 - B\sqrt{r_1}\log_e r_1$$

For maximum corona voltage, $\frac{\partial V}{\partial r_1} = 0$

$$\left(A + \frac{B}{2\sqrt{r_1}}\right)(C - 1 - \log_e r_1) - \frac{B}{2\sqrt{r_1}} = 0$$

$$C - 1 - \log_e r_1 = \frac{B/(2\sqrt{r_1})}{A + B/(2\sqrt{r_1})}$$

For an approximate solution we may take

$$C - 1 - \log_e r_1 = 0$$

since $A(= 55\cdot 5)$ is usually large compared with $B/(2\sqrt{r_1})$.

The accurate solution of the equation

$$C - 1 - \log_e r_1 = \frac{B/(2\sqrt{r_1})}{A + B/(2\sqrt{r_1})}$$

may be obtained by first solving

$$C - 1 - \log_e r_1 = 0, \text{ i.e. } \log_e r_1 = C - 1$$

and then taking other values of r_1 near to that thus obtained and solving graphically for r_1.

Example.—Take $r_3 = 3$; $r_2 = 2$.

$$C = \tfrac{4}{5}\log_e 2 + \tfrac{1}{5}\log_e 3 = 0\cdot 775$$

Taking $C - 1 - \log_e r_1 = 0$, we obtain $r_1 = 0\cdot 798$ in.

$$C - 1 - \log_e r_1 - \frac{B/(2\sqrt{r_1})}{A + B/(2\sqrt{r_1})} = F, \text{ say}$$
$$= -0\cdot 108 \text{ when } r_1 = 0\cdot 798$$
$$= +0\cdot 028 \text{ when } r_1 = 0\cdot 7$$

Plotting these values (Fig. 46) we get the correct solution of the equation as $r_1 = 0\cdot 72$, which agrees with the value shown in Fig. 17.

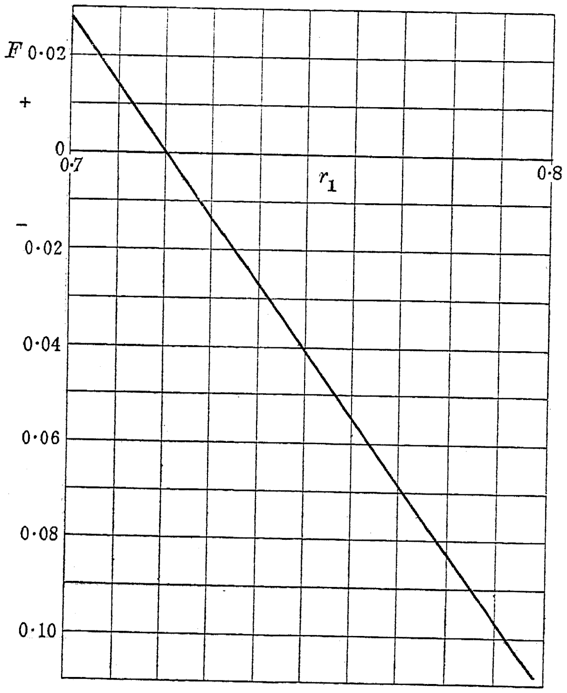


FIG. 46.

APPENDIX III.

RADIAL STRESSES IN BUSHING HAVING THREE DIFFERENT DIELECTRICS IN CYLINDRICAL FORMATION (SEE FIG. 24).

$$v = g_x x \epsilon_x\left[\frac{\log_e(r_2/r_1)}{\epsilon_1} + \frac{\log_e(r_3/r_2)}{\epsilon_2} + \frac{\log_e(r_4/r_3)}{\epsilon_3}\right]$$

in which r_3 and r_4 are assumed fixed, and r_1 and r_2 are variable.

Let
$$\frac{\log_e (r_4/r_3)}{\epsilon_3} = A$$
then
$$v = g_x x \epsilon_x \left[\frac{\log_e (r_2/r_1)}{\epsilon_1} + \frac{\log_e (r_3/r_2)}{\epsilon_2} + A\right]$$
$$= g_x x \epsilon_x \left[\frac{1}{\epsilon_1} (\log_e r_2 - \log_e r_1) - \frac{1}{\epsilon_2} \log_e r_2 + B + A\right]$$
where
$$B = \frac{1}{\epsilon_2} \log_e r_3$$
When $x = r_1$, gradient $= g$ (say),
$$v = g r_1 \epsilon_1 \left[\log_e r_2 \left(\frac{1}{\epsilon_1} - \frac{1}{\epsilon_2}\right) - \frac{1}{\epsilon_1} \log_e r_1 + B + A\right]$$

$$\frac{\partial v}{\partial r_1} = g \log_e r_2 - g \frac{\epsilon_1}{\epsilon_2} \log_e r_2 - g - g \log_e r_1 + (B + A) g \epsilon_1$$
$$\frac{\partial v}{\partial r_1} = 0$$
when
$$\log_e r_1 = \log_e r_2 - \frac{\epsilon_1}{\epsilon_2} \log_e r_2 - 1 + (B + A)\epsilon_1$$
i.e.
$$r_1 = \frac{1}{e} r_2^{(1-\epsilon_1/\epsilon_2)} r_3^{(\epsilon_1/\epsilon_2 - \epsilon_1/\epsilon_3)} r_4^{(\epsilon_1/\epsilon_3)}$$

This equation gives the relation between r_1 and r_2 which results in minimum electrostatic stress at $x = r_1$ for given values of r_2, r_3, r_4, and the applied voltage v.

APPENDIX IV.

STATISTICS OF RAINFALL.

The following table (taken from "The Rainfall of the British Isles," by Mr. De Carle S. Salter) gives a selection of the most remarkable falls recorded for the British Isles.

Date	Place	County	Amount	Duration		Rate of precipitation	
			in.	hrs.	mins.	in./hr.	mm/min.
August 10, 1893	Preston	Lancashire	1·25	0	5	15·00	6·35
June 14, 1917	Norwich	Norfolk	0·47	0	2½	11·28	4·78
May 8, 1812	Alexandria	Dumbarton	0·26	0	1½	10·40	4·40
March 24, 1888	Chepstow	Monmouth	0·33	0	2	9·90	4·18
August 2, 1906	Guildford	Surrey	0·89	0	8	6·68	2·82
May 30, 1902	Cambridge	Cambridge	1·10	0	10	6·60	2·81
August 7, 1875	Canterbury	Kent	2·12	0	20	6·36	2·68
August 14, 1914	St. Peter Port	Guernsey	1·50	0	15	6·00	2·54
July 22, 1880	Cowbridge	Glamorgan	2·90	0	30	5·80	2·45
June 23, 1878	Camden Square	London	2·30	0	28	4·93	2·08
July 12, 1901	Maidenhead	Berkshire	3·63	1	0	3·63	1·54
July 27, 1904	Cooling	Kent	2·66	0	45	3·55	1·50
July 29, 1901	Wadhurst	Sussex	3·25	0	55	3·55	1·50
May 30, 1903	Beddington	Surrey	3·50	1	0	3·50	1·48
June 26, 1895	Marlborough	Wiltshire	2·71	0	50	3·25	1·38
May 26, 1911	Fareham	Hampshire	3·00	1	0	3·00	1·27

Other Countries.

Country	Town	Year	Rate of precipitation	
			in./hr.	mm/min.
Panama	Porto Bello	1911	49·30	20·8
Germany	Füssen	1920	37·30	15·8
Rumania	Curtea de Arges	1889	24·10	10·2
U.S.A.	Galveston	1871	16·71	7·1
France	Bordeaux	1893	10·40	4·4
France	Molitg les Bains	1868	8·00	3·4
France	Paris	1888	7·08	3·0

Falls of the amounts recorded in these tables are exceedingly heavy and come under the category of cloud-bursts. One of the heaviest rainfalls recorded in these latitudes occurred in Germany on the 6th July, 1906, and yielded 130 mm of rain in 21 hours, i.e. 0·1 mm per minute on the average. A still heavier storm, lasting 6 hours, occurred in Dresden on the 5th July, 1918, the intensity of which at times equalled the heaviest ever recorded in Germany. In this case the following hourly amounts were observed:—

From 4 to 5 p.m. 17·4 mm, i.e. an average of 0·29 mm per min.

From 5 to 6 p.m. 29·9 mm, i.e. an average of 0·50 mm per min.

From 6 to 7 p.m. 20·1 mm, i.e. an average of 0·33 mm per min.

From 7 to 8 p.m. 12·7 mm, i.e. an average of 0·21 mm per min.

From 8 to 9 p.m. 19·3 mm, i.e. an average of 0·32 mm per min.

From 9 to 10 p.m. 4·1 mm, i.e. an average of 0·07 mm per min.

The maximum rate of precipitation was 4·7 mm per min. between 6.11 and 6.12 p.m.

Statistics of rainfall show that:—

Precipitation at the rate of 5 to 7 mm per min. usually lasts 1 to 2 minutes.

Precipitation at the rate of 4 to 5 mm per min. usually lasts 6 to 15 minutes.

Precipitation at the rate of 2 to 3 mm per min. usually lasts 16 to 30 minutes.

Precipitation at the rate of 1·5 to 2 mm per min. usually lasts 16 to 60 minutes.

Precipitation at the rate of 1 mm per min. usually lasts 2 to 3 hours.

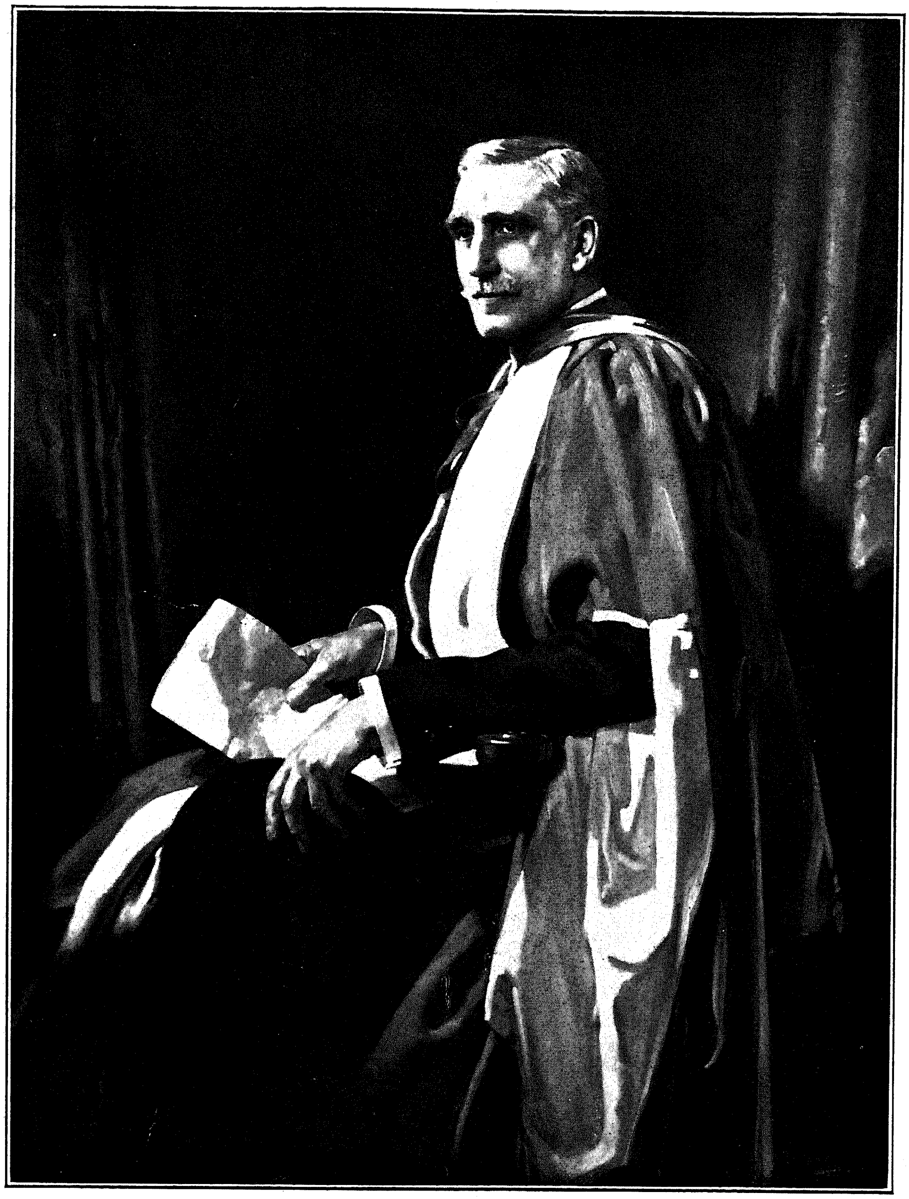
DISCUSSION BEFORE THE INSTITUTION, 3RD DECEMBER, 1931.

Mr. A. Collins: In my opinion the outstanding features of the paper are Table 9 and Appendix I. The trend of commercial bushing design has not resulted so far in the relationship between the minimum wet and dry flash-over values recommended by the author. In Tables 25 to 29 inclusive, particulars are given of various types of bushings. These tables not only include the work of several manufacturers employing different types of construction, but they also cover a wide range of working voltages. In every case the published dry flash-over figure exceeds the wet flash-over figure by considerably more than 20 000 volts. It is true that Tables 23 and 24 show that the author has approximated to this characteristic in certain air-core and compound-filled bushings which he has designed, but those for which figures are given are for comparatively low working voltages. It would appear that practical considerations have as yet prevented the relationship between wet and dry flash-over values at which the author arrives in Appendix I, and I should be glad if he would amplify this in the light of the tables to which I have referred. The use of mains water for wet tests is unsatisfactory. An installation that will provide artificial rain having the desired standard resistivity is a comparatively simple matter, and purchasers of bushings are justified in insisting that tests should be carried out under such conditions, quite apart from the fact that designers who rely upon correction factors and make their tests with mains water are liable to obtain misleading results. I regard the figures in Tables 20 and 22 as optimistic. Approximately 600 amperes is the maximum current usually carried continuously through a 1-in. copper conductor, and in spite of the test figures given in Table 22 experience shows that it is desirable to change over to flanges of non-magnetic material when the current exceeds about 400 amperes. The relative merits of the oil-filled and the condenser-type constructions have always proved an interesting subject of discussion. The author is to be congratulated upon the balance which he has preserved in this section of the paper. Both types of construction have been used for many years up to the highest voltages with satisfactory results, but there have always been two schools of thought, opinions usually being governed by the actual experience of the individual. Bushings are also manufactured in which the condenser construction is used in conjunction with an oil filling instead of a compound filling between the porcelain shell and the condenser bushing. For such bushings it is claimed that it has been possible to embody the advantages of either type. As to the condenser type, the troubles which have been experienced in the past have been almost entirely mechanical, consisting mainly of porcelain failures. This type of bushing has a relatively small amount of filling, so that the question of expansion, which the author emphasizes on pages 320 and 321, is more easily handled. Moreover, a mechanical failure of the porcelain does not lead to an immediate electrical breakdown of the bushing. Cases are known where condenser bushings with compound filling have remained in service for an appreciable time after damage to the porcelain has been detected, thus enabling the supply to be maintained until a convenient opportunity occurred to replace the bushing. The author describes on page 328 a capacitance coupling device built into an oil-filled bushing. It was probably not his intention to imply that this device is only employed in conjunction with the oil-filled construction. It has been the practice for some years to bring out connections from the condenser layers of bushings constructed on the condenser-type principle in order that a low-voltage supply may be available for the operation of potential-indicating devices.

Dr. E. H. Rayner: The first time I saw high-voltage outdoor bushings was a few years ago in Italy at a transmission-line centre at Brugherio, near Milan. The outdoor switch station, open at the sides, had a roof over it to protect the insulators—particularly from snow, I believe. This place was intended to develop into one of the major nodal points of the North Italian network of the Società Interregionale Cisalpina. Equipment for 130 kV was being installed. As a result of further experience, covered outdoor substations of that type may no longer be constructed; but the later large switch-room of the Mese station at Chiavenna, north of Como (which was visited on the occasion of the meeting at Bellagio of the International Electrotechnical Commission), shows that the Italians at that date had good reasons for enclosing their high-voltage terminal equipment. I should like to know what developments have since taken place in this direction. I hope that the bushing-insulator specification of the British Standards Institution will incidentally be the foundation for research, as many other British Standard Specifications have been. When such specifications are drawn up, manufacturers are sometimes inclined to over-estimate the ease of satisfying the requirements, and more detailed examination of factors of importance becomes necessary. We have now in hand at the National Physical Laboratory the equipment for testing bushing insulators. I have to thank the bushing-insulator and other manufacturers for putting at our disposal information as to dimensions, etc., of bushings of various ratings, in order that we might construct a special tank and fittings to take practically any size. I hope it will be ready in a few months. The author talks of dry flash-over and wet flash-over voltages, although it may be well to remember that these values should as a rule have little to do with the bushing itself. It is the separation of the arcing horns and ring which should determine the flash-over voltage, and naturally the discharge should not follow the surface of the porcelain rather than the arcing gap. The condition of the inside end of a porcelain bushing is important in connection with the " impulse " effects. The impulse flash-over voltage under oil between the conductor at the bottom of the bushing and the side of the tank can be considerably increased by the simple device of covering its end with a comparatively thick layer of paint. This can be done by placing round the end, which is usually of a spheroidal form, a knitted bag soaked in japan or some other paint which becomes hard.

Lieut.-Col. K. Edgcumbe: I am interested by the author's reference to the capacitance coupling for metering purposes, although I think that he is a little optimistic in this connection. While it is a very tempting proposition to replace a voltage transformer costing £100 or more by a piece of tin-foil wrapped round a bushing insulator, the problem bristles with difficulties. In Fig. 41, connected to the capacitance tapping, is a transformer which the author describes as a " potential " transformer. I hardly think that such a description is correct, because the instrument actually measures the charging current of the condenser through a current transformer, which is used in order to give a larger current through the instrument. This being so, the device is subject to all the troubles associated with the charging current of the condenser. In the first place, for correct measurement, the frequency and the capacitance must both be constant, but with such dielectrics as oil, porcelain, or paper, the permittivity and therefore the capacitance is dependent upon the temperature. Again, the charging current depends largely upon the wave-form of the supply, i.e. upon the harmonics present. About 10 per cent of a fifth harmonic gives an increase of approximately 12 per cent in the charging current, leading to a corresponding error. In addition, there are troubles arising from leakage and from stray capacitance to earth, the latter varying from day to day, chiefly owing to the capacitance of the moisture films which settle down on the bushing of the tapping itself. Altogether there are so many difficulties that, while the scheme is extremely useful for synchronizing or even for working relays, I do not think that it is of sufficient accuracy for metering purposes. I agree with the author that the multi-turn current transformer placed inside the bushing has much to recommend it from the point of view of the current transformer, but has the scheme the support of the supply engineer? To provide a high-voltage bushing with a large factor of safety and then to introduce an earthed conductor inside it seems to me to be a dangerous step. At the same time, I should be glad of further particulars of the arrangement illustrated in Fig. 39.

Mr. J. Venters: I should be glad if the author would explain why the flash-over voltages in Table 5 for transformers for an earthed-neutral transmission system differ from those for an insulated-neutral system. Since the normal phase voltage to earth of a system with an insulated neutral is the same as that of a similar system of the same line voltage having its neutral earthed, it would seem that the size of bushing should remain unchanged whether the system is earthed or insulated at the neutral. The author mentions (page 302) that the line insulators of a transmission system will receive the full effect of any over-voltages that may occur. He states that in general no over-voltage having a higher value than the surge flash-over voltage of the line insulators can reach the transformer bushings, that this surge flash-over voltage is practically constant under wet and dry conditions, and that it is approximately twice the normal 50-cycle dry flash-over voltage. By the normal 50-cycle dry flash-over voltage he may mean the crest and not the R.M.S. value, but tests with which I have been associated show that the actual value when using a 25-microsecond wave is $1\cdot63E$ and not $2E$. For steeper wave-shapes, say 5-microsecond waves, the figure rises to $1\cdot8E$, but the value of $2E$ is never reached with line suspension-insulators. The author refers (page 304) to the placing of weak links in transmission-line insulators near the transformers, in order to protect the latter from over-voltages. In considering the grading of the insulators of a transmission system, the bushing insulator forms only one link in the chain, and it would seem that it is the link that should be considered last. The first step is to determine the 50-cycle flash-over voltage of the suspension insulators of the transmission line. This voltage should be made as high as is economically possible. Lightning discharges over line insulators last up to 100 microseconds, and as one cycle of a 50-cycle wave lasts 20 000 microseconds it is possible for a flash-over to occur near the zero point of the 50-cycle voltage wave and thus do no damage. If, on the other hand, a flash-over occurs when the 50-cycle voltage is near its crest value, a power arc may be produced which will last until the transmission line is switched out by its protective gear. Statistics of flash-overs obtained from actual tests in the field have been published in America during the last few years. All the lightning flash-overs of which records have been obtained are caused by high-voltage disturbances initiated at some point on the line from which surges travel away in both directions. The point to notice about these surges is that the crest voltage of the surge becomes less as it moves away from the centre of the disturbance. American engineers attribute this effect to corona losses.



SEBASTIAN ZIANI DE FERRANTI. 1864-1930.

PAINTED BY D. JAGGER, 1931.

PRESENTED TO THE INSTITUTION OF ELECTRICAL ENGINEERS
BY H. MARRYAT, 1931.

Near the centre of the disturbance there exists a surge of high voltage having a very steep tail. At a distance of several miles from the centre of the disturbance the surge has a lower voltage but a longer tail. This fact appears to be in conflict with the orthodox theory of the propagation of electrical waves along a conductor. The ideal position, therefore, for a transformer station is a point on the transmission line where thunderstorms do not occur; at such a point the transformers will be subject only to low-voltage long-tailed surges. It is unfortunately impossible to select such positions for substations, and therefore the insulation of the transmission line near substations must be designed to limit the crest voltage of the surges to values which will be harmless to the transformer insulation. This standard of insulation will generally be found to be less than that economically justifiable to keep lightning flash-overs of line insulators down to a minimum. I wish to make it understood that, because of the attenuation characteristics of lightning surges, it is not necessary to insulate the whole system so as to correspond to the transformer insulation. Full insulation may be provided between substations, provided that the surges permissible on the line are not allowed to reach the transformers. It is doubtful whether one weak link near each substation is a sufficient barrier against high-voltage surges. Suppose a surge is travelling towards a transformer station and that its voltage is just insufficient to cause a flash-over of the line insulators; if a weak link in the line insulation is provided near the substation, it will flash-over several microseconds after the crest of the surge has passed it, and the transformer will receive the full voltage and practically the whole of the energy of the surge. These considerations led to the decision, in a scheme with which I have been connected, not to insert weak links in the line, but to reduce the insulation for a mile on both sides of each substation by using one disc less on each insulator string. The dry 50-cycle flash-over voltage of these strings for a 132-kV system, as ascertained by test, is 455 kV (R.M.S.). This is much more than the figure of 340 kV (Table 8) given by the author for the flash-over voltage of a safety string on a 132-kV line. The latter figure may be sufficient for overhead lines in Great Britain, where lightning is rare and the necessity for a high degree of insulation is probably not so great as in other countries where lightning is of frequent occurrence. When surges are frequent a higher grade of transmission-line and transformer insulation should be employed. This argument suggests that there should be different standards of transformer insulation for different countries. It is easy to adapt line insulation to suit local conditions, but it is difficult to decide how the transformer should be designed to suit the line insulation. There is no known acceptance test that will simulate the surge conditions for which a transformer has to be designed, and the ordinary induced—or separate—source tests therefore have to be employed. The difficulty is to decide what test voltage will correspond to the maximum surge voltage the transmission line can carry near the substation without flashing-over, and it is a matter which concerns the user almost more than the transformer manufacturer. On the system with which I have been associated 300 kV was chosen as probably equivalent to the figure of 455 kV for the transmission-line insulators. This voltage of 300 kV is used both for the separate-source test for fully insulated transformers and for the induced-voltage test for graded transformers. A comparison with Table 2B may be of assistance. The test voltage of 300 kV gives $2 \cdot 65V$ instead of $2V + 1$, for the separate-source test on fully-insulated transformers, and $2 \cdot 27V$ instead of $1 \cdot 58V$ for the induced-voltage test on graded transformers. The expression $1 \cdot 58V$ for a 132-kV system gives a test voltage of 208 kV. I should like to know whether the author can assure us that transformers designed for 200 kV will be safe when used with the insulators referred to in Table 8, in countries where lightning is more severe than in Great Britain. As flash-overs should occur on the line rather than on the transformer, the bushings for the latter should have a higher flash-over voltage than the line insulators adjacent to the transformer. The impulse ratio of bushings is understood to be higher than that of line suspension-insulators; e.g. for a 25-microsecond wave the insulators have a ratio of 1·63 : 1, and the bushings about 1·9 : 1. Thus, for example, bushings of 390-kV 50-cycle flash-over voltage correspond to line-insulator strings of 455-kV flash-over voltage. This figure of 390 kV for transformer-bushing 50-cycle flash-over is again much higher than the author's figure of 275 kV (Table 9) for bushings for a 132-kV system with earthed neutral. He will, I think, agree that bushings of 275-kV 50-cycle flash-over voltage are inadequate for transformers which are to be connected to 132-kV transmission lines with present-day standards of line insulation.

Mr. J. F. Shipley: I should like to refer to the method of attaching bushings to transformers. My experience has been that cork, which most manufacturers use for this purpose, is not a very satisfactory material. I find that in tropical countries the cork perishes after one or two years, and if it is sent out in the form of spare parts and unprotected it invariably perishes in about two or three months. Cork gaskets for bushings of this kind should be sent out in sealed tin boxes. It is very difficult, however, to find a better material for the purpose than cork. Langite is a little too hard, and one is apt to break the bushings by trying to get an air-tight joint with it. The author's remarks with regard to methods of testing the wet flash-over voltage are interesting. The results one gets in a testing laboratory in this country are no indication of the flash-over voltage under severe conditions, especially in tropical countries; on the other hand, they are the best obtainable and one has to be satisfied with them. The wet flash-over voltages of insulators and bushings in tropical countries are almost exactly the same as the dry flash-over values obtained in the laboratory, due to the fact that the moisture produced by the condensation of water vapour from the atmosphere is so pure that it is a perfect insulator. This is also borne out by my experience that it is of no use to earth a system in a river, because the latter is a perfect insulator. It is difficult to obtain an earth connection without salting the water, because the latter is of such high resistivity. The author's figure (Appendix IV) for the rainfall of

Panama is the normal value for almost any wet tropical country within 10° of the equator. Dr. Rayner's reference to snow on insulators reminds me that once when I was in South Germany in the winter I inspected a transformer station the gable roof of which was loaded with 4 or 5 ft. of snow, while the voltage on the incoming and outgoing lines and insulators was 110 kV. During a thaw the whole of the load of snow fell on top of the two live circuits, and hung in deep festoons, but I did not see a single flash-over. With regard to the mounting of bushings on transformers, makers in this country are inclined to put them too close together. They forget that the transformers may be used abroad in countries where there are stick insects eight or nine inches long which like to get on to the insulator and wait for a moth to come along. This often leads to a flash-over. We have to insist that the high-tension terminals of transformers for tropical countries shall be placed three or four inches further apart than is the common practice over here. Another trouble is that transformers are inclined to flash-over the surface of the oil between a conductor and a tapping lead. While the trouble can be overcome by having the transformer completely oil-filled, this course is not always possible where transport arrangements are difficult.

Mr. S. W. Messent: The author's flash-over voltage figures do not agree with those based on theoretical considerations, because usually the metal cap on a bushing is not brought as near to the top porcelain shed as would appear from Figs. 3 and 42, upon which his thesis is based. This probably accounts for the fact that the growing difference between the wet and dry flash-over voltages shown in the tables on pages 325 and 326 is not confirmed by the formula given at the top of the second column on page 301. The curve shown in Fig. 8 is a better practical indication of the relationship between dry and wet flash-over values. The actual values the author gives for the flash-over voltages desirable for various working pressures approximate fairly closely to the British Standard Specification figures (see Table 10). I should like to know whether he finds these figures sufficient in practice, as I think that in general higher flash-over voltages are called for by most apparatus manufacturers, often at the instance of their customers. The theoretical treatment of the compound-filled bushing incorporating other insulating material is interesting, and the results of any experiments which have been carried out to determine the relative performance of the bushings detailed in Tables 18 and 19 would be instructive. The melting-point (90° C.) of the compound used in compound-filled bushings seems to be rather low. Is such a soft variety used because of the comparatively large amount present in such a bushing? It may be that harder compounds are not advisable because of the danger of the formation of cracks, particularly when—as may happen with a transformer on full load—the lower end of the bushing is maintained at a high temperature while the other end is subjected to frost. Under such conditions, when night generally brings a lowering of the outside temperature, there must be considerable risk of voids and cracks forming in the compound. In connection with the temperature/voltage characteristics of insulation other than porcelain, the author implies that it is unfortunate that varnish-paper insulation has a reduced electric strength with increase of temperature. Most bushing failures are due to flash-over rather than to punctures, and, as regards varnish-paper insulation baffles for oil-filled bushings, the thickness of these is determined as much by mechanical considerations as by electrical requirements. The wording of the paper would perhaps have been happier had the author stated that insulation of this type has a higher electric strength when it is cold than when it is hot, and that therefore under normal working conditions there is in general a higher factor of safety than is allowed for when designing the bushing. He admits the possibility of local discharge in an oil-filled bushing (see page 323) and states that varnish-paper barriers are to be deprecated because such an electrical discharge would damage their surface insulation. If such a local discharge did occur—and I am not sure that it could, unless it were due to bad design or workmanship—would it not affect the surface of porcelain just as much? As regards the relative merits of condenser-type and oil-filled bushings, one often finds that a supply engineer who has experience with oil-filled bushings thinks he would prefer the condenser type, and vice versa. Rigorous tests should be applied to all bushings, and I doubt whether the condenser type requires more searching testing than any other. Perhaps a little more care is needed in its assembly and manufacture, but on the other hand considerable technical skill and experience are required in the assembly of any bushing, including the oil-filled type. Troubles due to incorrect assembly of the latter are by no means unknown. The all-porcelain type of condenser bushing is interesting and I should appreciate any information the author can give concerning the material, if any, which fills the space between porcelain shells above and below the metal layers connected together by means of a conducting filling. Such a material has to follow and accommodate itself to the temperature changes and variations to which the bushing is subjected, without cracking or breaking contact with the porcelain surfaces to which it must adhere. If the space is left empty, are arrangements made to keep it dry and clean? It is assumed that there will of necessity be comparatively few condensers in this construction, so that the voltage across each will be considerable and will impose high stresses on the ends of the metallic layers. Has any difficulty been experienced due to this, and, if so, what measures have been taken to overcome it? The conditions are accentuated if the filling medium above the metallic layers does not seal the space completely, and more especially if means are not adopted to prevent the ingress of moisture.

Mr. W. P. Digby: I should like to ask a question concerning temperature-cycle tests on the condenser-type bushing. Obviously, alternate immersion in cold and hot water cannot be applied, but, if reversals of temperature are of any value in determining the utility of the porcelain bushing, something of a similar nature is required for the condenser type. I suggest that a suitable method of testing would be that of placing the condenser-type bushing in a vapour bath, which I have found to be of great value in discriminating between different classes of fibrous materials.

Mr. R. H. Abell (*communicated*): The preparation of the paper is timely, in view of the vast number of transformer bushings of different makes, types, and sizes which are now going into service. On page 303 the author gives a formula, based on operating experience, which connects 1-minute transformer tests and maximum permissible line-insulator flash-over voltages. It would be interesting to have a little more information in regard to the experience upon which this formula is based. I have used it to calculate the equivalent figure for "grid" lines, which I find to be 529 kV compared with the actual figure of 420 kV with a 9-unit string. The author refers to the use of weak links; the danger which I see in the introduction of weak links into line insulation is the possibility of an increased number of flash-overs at normal voltage when the line insulators have become coated as a result of operation in smoky or salt-laden atmospheres. This difficulty can, of course, be met by using the normal number of insulator units and reducing the distance between the arcing horn and ring. The following figures may be of interest in regard to the insulation provided on a section of the "grid."

Tension String. Dry flash-over voltage = 440 kV; wet flash-over voltage = 320 kV; arcing distance (horn to ring) = $52\frac{3}{4}$ in.

Nine-Unit Suspension String. Dry flash-over voltage = 385 kV; wet flash-over voltage = 320 kV; arcing distance (horn to ring) = $38\frac{1}{2}$ in.

Transformer. 1-minute test voltage = 360 kV.

Transformer Bushing. Minimum dry flash-over voltage = 400 kV; minimum wet flash-over voltage = 320 kV; flash-over voltage under oil = 450 kV; puncture voltage = 550 kV.

Provision has been made for additional insulators in certain districts when this is found necessary. In Table 20 the author gives interesting information in regard to the current-carrying capacity of the conductor in bushings. It is not clear whether this relates to the solid, compound-filled, or oil-filled type of bushing. Certain figures which I have recently obtained for 33-kV bushings are in several cases much higher. I feel that the author's figures are rather conservative. The fact that the final temperature-rise of $\frac{5}{8}$-in. diam. rod carrying 500 amperes is given as 23·5 deg.C. in Table 22, appears to confirm that the current could be increased considerably beyond the values given in Table 20. Although the author includes the $\frac{1}{2}$-in. diam. rod, experience shows that this size is mechanically unsatisfactory. I am interested in the author's experience with compound-filled bushings (page 319). I am of the opinion that this type of bushing should be avoided wherever possible. My own experience of compound-filled bushings has been unsatisfactory. The only justification that I can see for their use is that they are cheaper than the oil-filled type, but for 33 kV I definitely advocate the use of oil-filled in preference to compound-filled bushings. One of the difficulties associated with compound-filled bushings is the expansion of the compound, which forces its way out of the bushing and then contracts when the transformer is only lightly loaded. This effect will probably cause the porcelain to crack and the compound to enter into the oil, the result being a bushing failure. On page 323 the author describes the construction of oil-filled and condenser-type bushings. Our experience with the former has been entirely satisfactory; in not a single case have they failed us in service. Our experience with the condenser type has also been satisfactory, but on one occasion we have had difficulty on account of the entry of moisture. This experience would seem to be contrary to the author's opinion that the condenser-type bushing is easier to make weather-tight. We shall all be interested in the new all-porcelain bushing described on page 324, which incorporates the condenser principle. Table 29 appears to show that with this design the author has secured adequate control over the ratio between the wet and dry flash-over voltages. Its weight and dimensions appear to be comparable with those of other types of bushings for the same service. I feel a little concerned in regard to the necessity for filling the space between the metallized surfaces of each porcelain tube, as it would appear to be an extremely difficult matter to obtain a suitable filling. I should like to make an appeal for the standardization of bushing dimensions, a question which might well receive the attention of the leading transformer-bushing manufacturers. I am in favour of standardizing the principal mechanical dimensions, such as the inside and outside diameter of the flanges, the diameter of the hole in the tank, the pitch-circle diameter, the number of securing bolts, the length of the bushing under oil and the length of the bushing outside the tank, the diameter of the conductor, and the form of fitting. Standardization of this kind would help the electric supply industry in this country and would be of great value to the British bushing manufacturers, who would reap the benefit of it in the export market.

Mr. H. Trencham (*communicated*): The author's comments on test requirements bring to light a considerable variation in demand. This variation appears somewhat unfortunate in view of the trouble which has been taken to ensure that the British Standard Specification shall be truly representative of British requirements. As regards wet flash-over voltages, the wet flash-over characteristic is not likely to be permanent in service, irrespective of the resistance of rain water; deposits of dirt, salt-spray, etc., can very materially reduce the clean flash-over figure. In order to meet this condition many engineers specify bushings with a long creeping surface, or with a higher flash-over value than is usual for the voltage in question. The use of an arcing horn on the bushing itself has been resorted to on many occasions, as by this means a correct relationship can be established between the various flash-over and puncture values. This arcing horn may, in effect, comprise the weak insulation link referred to in the paper. Whilst bushings for transformers are the main subject of the paper, it should be pointed out that economy in manufacture favours the use of similar components for both circuit breakers and transformers, the needs of which should also be taken into account when bushing problems are under discussion. Whereas the author on page 299 finds no definite grounds for deciding whether puncture or internal flash-over should take place first, the requirement of circuit breakers is undoubtedly best met by having the puncture strength higher than either the internal or the external flash-over voltage. It would have been of interest had the author considered the question of puncture strength in a little more detail. Normal design does not permit of a puncture test being carried out at service frequency if the puncture voltage is higher than the internal flash-over voltage. Impulse testing, however, may give a different result, and certain cases are known to the author where mysterious punctures occurred on bushings which should have flashed-over prior to puncture. It is probable that the impulse ratio is lower for puncture than for flash-over, and a knowledge of the relative values would be of interest. As regards temperature-cycle testing (page 310), it would be of interest to have the author's opinion as to whether insulators on which the temperature-cycle test has been carried out are safe to employ in service. The statement on page 311 that compound is self-healing should, I think, be qualified, as compound is only self-healing when soft. In circuit-breaker operation the compound in bushings may frequently be found to operate at a temperature sufficiently low to allow a comparatively hard compound to remain in that condition. In connection with oil-tight gasket joints (page 319), I would point out that jacking screws should be provided on the fixing flange. Without such screws there is a danger either that the gaskets may be over-compressed and become disintegrated, or that if the gaskets are hard enough to withstand extreme tightening, there may be over-stressing of the porcelain. I should like to mention an additional reason for heating bushings, etc., prior to compound filling (see page 320). If compound is poured into a cold chamber there is a danger that it may merely roll up the walls, without actually "wetting" them. Referring to the heating and cooling of compound in bushings (page 321), the inverse of the cycle described may take place in oil circuit-breakers, and this necessitates that the bottom joint of the bushing should be not only compound-tight but also oil-tight. I understand that certain Continental manufacturers omit the hollow paper cylinders from oil-filled bushings. Can the author confirm this, and, if so, is he able to comment on the relative experience with the Continental design and that common in the U.S.A. and this country, where hollow paper cylinders are used? Turning to the comparison between oil-filled and condenser bushings, it should be pointed out that in the case of failures during test or faults in manufacture, the loss incurred through the breakdown of an oil-filled bushing is very much less than is the case with condenser bushings. Also, the construction of the oil-filled bushing is such as to allow of easier and cheaper maintenance work. It would be of interest if the author would describe in what way the insulation between primary and secondary is obtained in the construction shown on page 328. The construction of a wound transformer for high voltages is by no means easy, and the additional complication of tapping the primary seems to be of questionable wisdom. In the type of bushing illustrated in Fig. 32 it is readily possible to produce secondary taps to cover ranges of ratio from 50 : 5 to 250 : 5. Recent improvements in the design of such transformers enables them to be built with surprisingly accurate characteristics, notwithstanding the small number of primary ampere-turns.

Mr. W. J. John (*in reply*): Replying to Mr. Collins, the relationship between dry and wet flash-over voltages given in Appendix I expresses the maximum nearness of approach of the wet to the dry flash-over value. The margin between dry and wet flash-over can be increased to almost any extent by modifying the contour of the bushing. While Tables 25 to 29 show that accepted commercial practice gives a different relation between the two flash-over voltages, I believe that the wet flash-over voltages given in these tables could in all cases be raised to satisfy the relationship established in Appendix I, and this without any serious loss of other desirable characteristics. That this has not been done in practice is probably due to the fact that the dry flash-over voltage largely determines the value of the surge flash-over voltage under both dry and wet conditions. The practice appears to have been to fix the dry flash-over voltage at a figure which ensures desirable minimum surge flash-over characteristics, and to allow the wet flash-over voltage to be less than the maximum obtainable from the design. I agree with Mr. Collins's remarks as to the unsatisfactory nature of wet tests carried out with mains water.

Dr. Rayner's remarks concerning Italian bushing practice are very interesting. I endorse his hope that the new British Standard Specification for bushings (B.S.S. No. 223—1931) will foster bushing research. The new bushing-testing equipment at the National Physical Laboratory should be of great assistance in developing improved bushing technique.

I accept Col. Edgcumbe's correction as to my use of the term "potential transformer" in describing the transformer joined to the capacitance tapping in Fig. 41. In the main, I agree with his reasoning concerning the difficulty of using the charging current of a condenser for operating metering equipment. In my opinion the capacitance tapping is not a serious competitor of the ordinary potential transformer for accurate metering purposes; but where the frequency is accurately controlled and the voltage is of good and constant wave-form, and where great accuracy is not required, the capacitance tapping may have an application for metering purposes. Possibly variations of frequency and temperature could be automatically compensated for in the meter itself. The main use of the capacitance tapping at the present time is to provide a voltage for synchronizing and for relay operation. For these purposes it is an undoubted success. Multi-turn current transformers placed inside the bushing are being supplied in large numbers because of their many advantages, and I think there is no question as to the favour with which this practice is viewed by supply engineers. These current transformers are usually employed in oil-filled bushings sectionalized at the earth flange, as shown in Fig. 32. It is customary to provide them with an earthed shield which is connected to the flange of the bushing. In effect this amounts to bringing the earth flange closer to the centre conductor, a point which must be allowed for in the design. There is, however, no question of introducing an earthed conductor inside the bushing as a new feature.

In reply to Mr. Venters, Table 5 was compiled from considerations based on 1-minute test values, and since these are different according as the neutral is earthed or insulated, the flash-over figures are also different. The information given by Mr. Venters regarding surge flash-over voltages of insulators is interesting, and I accept his figures of $1 \cdot 63E$ to $1 \cdot 8E$ instead of the approximate value $2E$ given in the paper. His remarks on the probable behaviour of a surge in connection with a weak link are, I believe, correct. However, although the full peak of the surge may reach the bushing, its time of application to both bushing and transformer insulation will be of short duration due to the flashing-over of the weak link. I agree that the more weak links there are, the greater will be the protection afforded to the transformer. Mr. Venters points out the difference between the figures for 132-kV insulation as given in the paper (340 kV) and in practice (455 kV). I would emphasize that the figures for line insulation used in the paper are based on B.S.S. No. 137—1930, while in practice the line insulation should be of as high a grade as is economically possible. Many transmission lines are insulated to higher flash-over values than that laid down in B.S.S. No. 137—1930, and the bushing characteristics must, of course, be studied in their relation to the actual line-insulator characteristics. This frequently results in higher bushing flash-over voltages than those given in the paper. Table 9 gives recommended flash-over voltages for bushings and insulators as based on British experience only, and I agree with Mr. Venters that there should be different standards of transformer insulation for different countries.

Mr. Shipley's first-hand knowledge of bushing operation in tropical countries is very valuable, and I should like to thank him for his remarks.

Mr. Messent refers to the difference between practical results and the flash-over figures given in the paper. These figures are minimum ones to comply logically with British Standard Specifications. It is considered undesirable to use lower figures than these, but higher flash-over figures are, of course, possible and they give increased freedom from shut-down. The decision as to how much (if at all) the actual flash-over figures are to be greater than the minimum, must be made separately for each individual case. Soft compound was used as a filling material for the reasons Mr. Messent suggests. Hard compound should not be used in bushings of the type described in the paper. Regarding the action of local discharges in oil-filled bushings, I am of opinion that unless these are very pronounced they would not harm porcelain tubes, whereas they would impair varnish-paper tubes. In reply to Mr. Messent's question regarding the porcelain type of condenser bushing, the filling between tubes is an insulating compound. This is short-circuited by the metallic connection between the condenser coatings on adjacent tubes, and so has no definite electrical function, but it keeps the space both dry and clean. No difficulty has arisen in practice due to the stress on the ends of the metallic layers, possibly because these are embedded in the compound already referred to.

Mr. Digby's suggestion concerning temperature-cycle tests on condenser bushings is a valuable one.

In reply to Mr. Abell, the formula on page 303 simply correlates B.S.S. No. 171—1927 and B.S.S. No. 137—1922. No other information was available in a form which could be regarded as based on operating experience. Much investigatory work would have to be done before the validity of this or any similar formula could be definitely established. The difference between the figures of 529 kV and 420 kV mentioned by Mr. Abell means that "grid" transformers should be operating with an increased safety factor, assuming that the formula is correct. The figures which he gives for the grid lines are of interest. Tables 20 and 22 refer to air-core all-porcelain bushings, and the results given in Table 22 were obtained by passing the current through a bushing supported in air. The lower part was not placed in hot oil, as it would be in practice. This accounts in part for the fact that the figures in Table 20 appear conservative. Regarding compound-filled bushings, there should be no danger of compound being forced out of the bushing as the temperature is raised. The bushing is filled with hot compound (much hotter than it will be when in operation) and an expansion space will be created at the top of the bushing on cooling. This expansion space can be increased if necessary by incompletely filling the bushing with the hot compound. A properly made compound-filled bushing should be quite satisfactory, and the advantage of cheapness is important. Regarding the porcelain-type condenser bushing, the filling of the spaces between the tubes has not given rise to any difficulty. I endorse Mr. Abell's views as to the desirability of standardizing bushing dimensions, and I hope that the necessary machinery for accomplishing something along these lines will be set in motion.

I am interested to note from Mr. Trencham's remarks that bushings for oil circuit-breakers should have puncture strengths in excess of oil-end flash-over. As regards temperature-cycle testing, there is no obvious reason why bushings which have successfully passed this test should not be placed in service. I agree with Mr. Trencham that only soft compound can be regarded as self-healing.

MULTI-CHANNEL TELEVISION.

By C. O. BROWNE, B.Sc.

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SUMMARY.

An experimental television system designed expressly to examine the conditions necessary for the transmission and reception of comparatively good pictures is described.

Five picture channels are used which accommodate a frequency band sufficient to produce an image composed of 15 000 elements. The received picture is projected on to a screen measuring 24 in. by 16 in., and is scanned at the rate of 12½ times per second.

The best operating conditions for the Kerr cells of the receiver are investigated, and the effects of geometric, non-linear, and frequency distortion are examined.

INTRODUCTION.

In contriving to produce a new system of television, one of two limitations must be observed throughout the design. Either we must realize the practical limitations imposed by the very limited frequency band it is possible to transmit along one channel from the transmitter to the receiver, and design apparatus to accommodate only this range of frequencies, or we must disregard this practical limitation and attempt to produce correspondingly better results at the expense of a number of transmission channels.

The latter option has been taken in the design of the television apparatus described in this paper, in the development of which known results have been used as far as possible, only a comparatively short period having been spent in breaking new ground. The construction of the apparatus was undertaken mainly for the purpose of investigating the problems associated with the transmitter and receiver, and for examining the electrical and optical conditions necessary in the picture channels in order to secure good results. In order to achieve this end without introducing further difficulties, land lines were used as the connecting link between the two stations.

The total frequency band necessary to transmit a given picture may, in the case of a multi-channel television system, be divided into a number of channels, each of which accommodates a frequency band given by the total frequency range divided by the number of channels. On this account the difficulties of design, not only of the apparatus situated at the transmitter and receiver but also of the transmission link between the two stations, are considerably reduced. Apart from this advantage of the multi-channel system, the amount of light available for illuminating the receiver screen is increased in proportion to the number of channels used. Further, the velocity with which the scanning spots travel over the surface of the picture to be transmitted is decreased, so that the accuracy necessary for synchronizing is reduced as the number of channels is increased.

In order that the received picture should contain a tolerable amount of detail and represent an appreciable advance on existing television pictures, it was considered necessary to compose it of at least 15 000 picture points. In this connection a picture point was considered to be the smallest element of the picture on the receiver screen resolvable by the eye when viewed from a given distance, and in subsequent calculations for the frequency band necessary to transmit a 15 000-point picture it was considered unnecessary to take into account harmonics of frequencies corresponding to this limit of resolution, which might, for instance, be introduced by a sharp edge.

Before proceeding with the design of the amplifiers or, in fact, of any other part of the system, a rate of scanning had to be decided upon. From previous experience it had been found necessary to scan at least at the rate of 12 times per second; a speed of 12½ times per second was therefore chosen and the design of the scanning mechanism provided that this speed could be increased subsequently if desired. The precise speed of 12½ pictures per second was chosen because 50-cycle a.c. mains could then be used without the inclusion of awkward gear ratios, although, of course, provided the same reduction ratio was used between the synchronous driving motors and the scanning devices at the transmitter and receiver, the transmitter and receiver would still run in synchronism.

It will be seen that in a picture containing maximum detail, i.e. in which the picture elements are alternately dark and light, one cycle would be represented by a dark and an adjacent light element, so that one cycle comprises two picture elements. The frequency range necessary for transmission is thus $12\frac{1}{2} \times 15\,000 \times \frac{1}{2}$ or 93 750 cycles per second, but since an intermittent motion was to be used at the transmitter a factor had to be introduced to allow for transversal of pictures between scanning operations. This factor amounts to 5/4, which represents the ratio of the duration of the total picture cycle to the time the picture is stationary while being scanned. The frequency band is therefore increased to $93\,750 \times 5/4$, or approximately 117 000 cycles per second.

A picture of which the main dimensions were in the ratio of 3 (width) by 2 (height) was chosen, the specific dimensions to be determined subsequently when the amount of light available for illuminating the receiver screen was known.

For the reasons mentioned previously it was decided to divide this frequency range into a number of equal bands each of which was to be transmitted separately and simultaneously. In view of the practical difficulties involved both in the use of amplifiers working from photo-electric cells and in the use of Kerr cells, the highest frequency necessary to be transmitted in each channel was limited to 25 000 cycles per second, and five picture channels between the transmitter and the receiver were therefore chosen to accommodate the picture signals. This means that, measuring the amplitudes of the modulated light input to the photo-electric cells and of the modulated light output from the Kerr cells, the amplifiers and transmission system should be level in frequency response from zero to 117 000 cycles per second divided by 5 (the number of channels), or 23 400 cycles per second. This condition does not, of course, take into account the effective loss at the upper frequencies due to the finite size of the scanning spots both at the transmitter and at the receiver, but these losses can be calculated and compensated for in the amplifiers.

THE TRANSMITTER.

It was decided to use cinematograph film bearing the subject to be transmitted, mainly because film is plentiful and it enables the conditions existing at any particular transmission to be repeated with comparative accuracy on any subsequent occasion. A further advantage accrues in that it is possible to illuminate film with an arc and, therefore, to obtain more light for the scanning process at the transmitter.

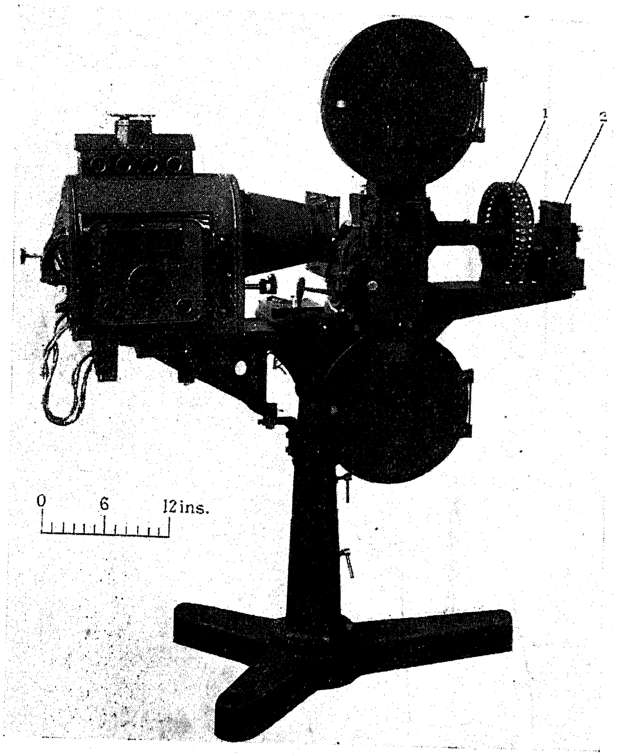

FIG. 1.—Projector and scanning mechanism.

In the design of the transmitter a choice could be made between two methods of scanning. First, the film could be kept in continuous motion, using this motion as one direction of scanning; or, secondly, the film could be moved intermittently and be scanned in two mutually-perpendicular directions while stationary. The second of these methods was chosen because the continuous-motion method involves the use of such perfect gearing between the film and the scanning device that the errors in the positions of scanning lines do not exceed the width of a line, which is hypothetically the limit of resolution of the eye at the receiver screen. It is doubtful whether after a limited number of traversals of one length of film through the apparatus the accuracy of the perforations would be good enough to satisfy this condition. In the case of the intermittent motion, however, which is provided by a Maltese cross, the film is stationary during scanning and, moreover, even with a defective mechanism the film obtains identical framing in the gate at every fourth picture.

Fig. 1 gives a general idea of the illuminating, scanning, and mechanical part of the transmitter, in which a standard cinematograph projector with but slight modifications has been used. The shutter-blade shaft completes a revolution during every picture cycle and was chosen to drive the scanning mechanism, which consists of a drum (1) provided with a spirally-arranged set of lenses mounted on its cylindrical surface. Connected rigidly to the lens-drum shaft is a small generator (2) which provides 1 250-cycle alternating current for synchronizing purposes when revolving $12\frac{1}{2}$ times per second. In order that irregularities of load due to the intermittent mechanism or imperfect gearing may not give rise to irregular motion of the lens drum, a spring coupling is inserted between the projector and the scanning and synchronizing mechanism. This, together with the mass of the bronze lens-drum, constitutes a mechanical filter, and, to prevent the latter from oscillating, the container for the spring coupling is provided with baffle plates and encloses grease as a damping medium. As the extra load of the lens drum and generator would have been too great to be driven through the gearing of the projector mechanism, the drive was taken from a synchronous motor through a chain and sprockets to the shutter-blade shaft.

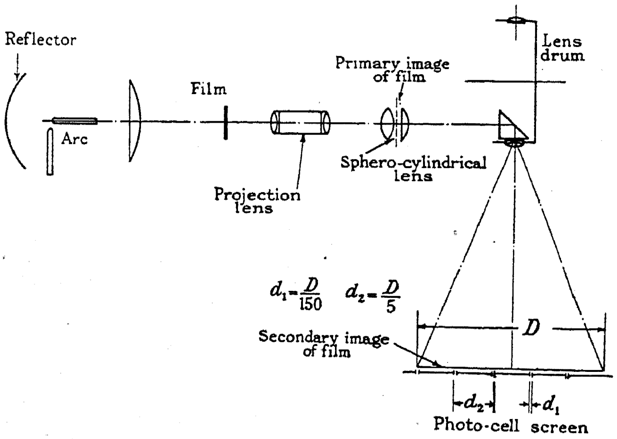

FIG. 2(*a*).—Transmitter optical system with lens drum.

Fig. 2(*a*) is a diagrammatic representation of the transmitter optical system, and Fig. 2(*b*) shows an alternative arrangement providing mirror-drum scanning. A lens drum was first used chiefly because suitable lenses were readily obtainable, but a mirror drum was substituted subsequently for reasons which are discussed later.

Referring to the details of the optical system, a projector lens forms an enlarged image of the film at a sphero-cylindrical lens combination and secondary images of the film are thrown—after reflection by a right-angle prism—on to the photo-cell screen by the lens drum. The sphero-cylindrical lens provides that two adjacent lenses of the lens drum are filled with light, so that there is no discontinuity in illumination at the photo-cell screen.

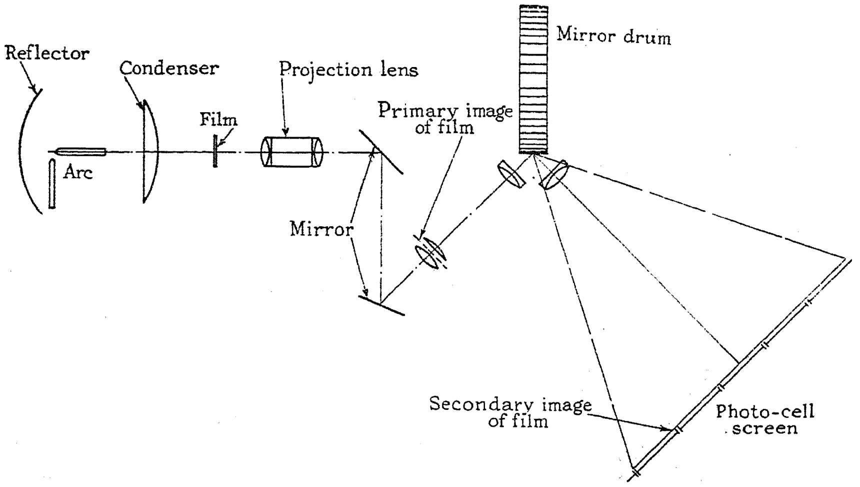

FIG. 2(*b*).—Transmitter optical system with mirror drum.

The images formed by the lens drum are 30 in. wide and overlap the photo-cell screen in the manner indicated in Fig. 2(*a*). The pitch between lenses is such that each image is displaced by the width of a scanning line from its predecessor, and after the traversal of 30 lenses the total displacement is 30 lines, or one-fifth of the width of the image. The magnification of the optical system was so chosen that the top of one picture is adjacent to the bottom of the preceding picture, there being no space between successive pictures. In order to facilitate focusing, the whole lens drum is movable axially along its hollow shaft. Fig. 3 is a sketch showing the relative positions of the photo-cell screen and the remainder of the transmitting mechanism.

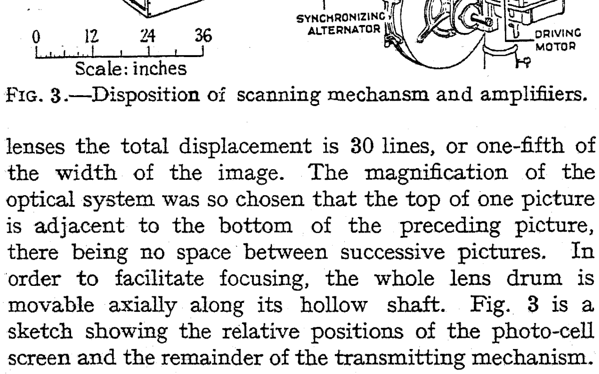

FIG. 3.—Disposition of scanning mechansm and amplifiers.

Although 30 lenses are used in the lens drum for scanning purposes, actually 38 lenses are included, 8 of these being operative during picture-changing. These extra lenses serve a dual purpose. First, they eliminate the necessity for critical adjustment between lens drum and intermittent mechanism; in other words, the scanning is equally good whether performed by the 2nd to the 32nd lenses or by the 4th to the 34th lenses. Any error in overlap on the photo-cell screen is corrected by swivelling the projector about its supporting column. Secondly, the photo-cells are illuminated continuously and a large pulse arising from the dark interval between the first and last lenses is not transmitted through the system once every revolution, as would be the case if a blank portion were included in the lens drum. A large pulse of this nature seriously overloads the amplifiers and Kerr cells.

AMPLIFIERS.

In order to ascertain the amplitude of the light derived from the scanned picture, a rough model of the transmitter optical system was constructed which included the actual lenses to be used in the complete apparatus. It was estimated that about 1 millivolt would be generated by an average picture across $0 \cdot 3$ megohm connected in series with a vacuum cæsium photo-electric cell which constitutes the beginning of the transmission channel.

A photo-electric cell of this type was chosen owing to the excessive attenuation which is introduced at the higher frequencies by gas-filled cells.* The voltage swing required to operate the Kerr cells used at the receiver is of the order of 600 volts double amplitude, so that the total amplification required between the photo-cells and the Kerr cells is 300 000 times, or 110 decibels.† Actually the amplifiers were designed to have a total magnification of 10^6 times, or 120 decibels.

Fig. 4 is a circuit diagram of the transmitter amplifiers corresponding to one channel. It will be noticed that they are divided into two sections, each section being fed from its own batteries, partly in order to prevent feed-back and partly for portability. The components of each section are mounted on teak, which in turn is placed on sorbo rubber held between iron brackets. Iron covers which push over each amplifier are effective as screens between the channels, and these are also lined with felt in order to prevent noise affecting the received picture through microphonic troubles. Further iron screening-covers are placed over the two sets of batteries feeding the two amplifier banks. All the amplifiers on each bank are identical and are readily interchangeable.

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* G. F. METCALF: "Operating Characteristics in Photo-electric Tubes," *Proceedings of the Institute of Radio Engineers*, 1929, vol. 17, p. 2064.

† It is convenient to measure the relative levels in the amplifier system in decibels, which, being logarithmic in nature, give a true indication of the effective brilliance or the depth of modulation of the pictures as seen by the eye.

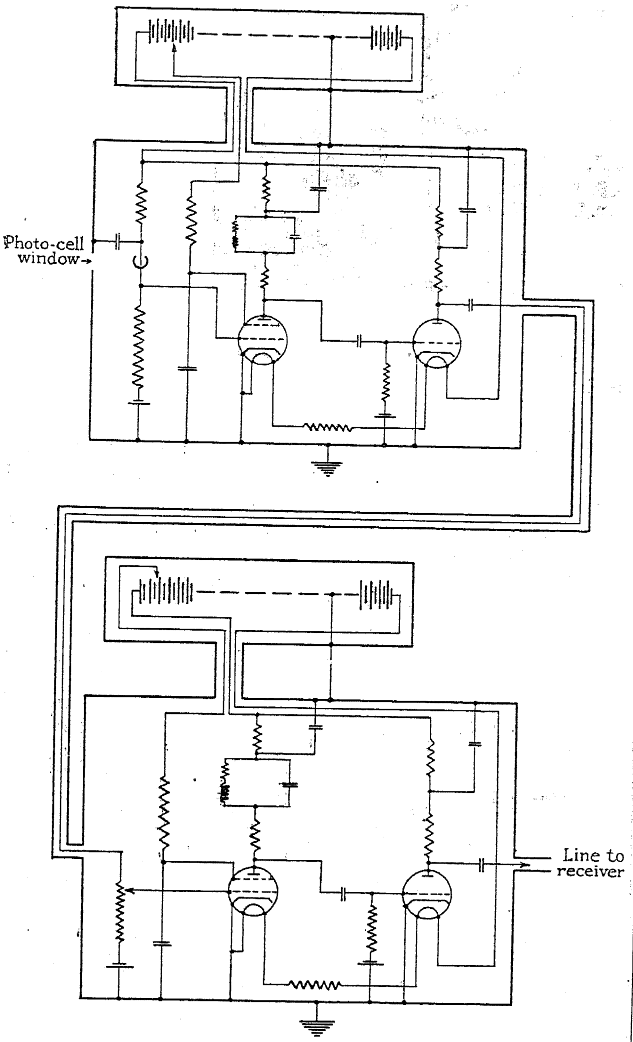

Fig. 4.—Transmitter amplifiers.

A potentiometer is included in each channel to regulate their individual outputs and to match up the amplitudes of the signals in each. The adjustment of these potentiometers, which are correctly graded logarithmically, is not critical.

A network tuned to approximately 30 000 cycles per second is included in the anode circuit of the valve following the photo-electric cell, in order to compensate for attenuation introduced by the latter at frequencies above 5 000. A similar network is included in the second bank of amplifiers to compensate in the same way for losses introduced by the Kerr cells and the transmission lines, the former being used at the receiver for modulating the scanning light beams.

These amplifiers were calibrated in the manner described later and the necessary amount of compensation was introduced by adjusting the values of the inductances, capacitances, and damping resistances of the tuned networks until satisfactory frequency characteristics were obtained.

The Receiver.

The general arrangement of the receiver is as shown in Figs. 5, 6, and 7, the latter being a diagram of the optical system. Light from an arc (5) is divided into five pencils by a prism and lens system (6) and each pencil is transmitted between separate plates of the Kerr cells (7), which are all immersed in a common bath of nitro-benzene. The beams are then reflected by the mirrors of a mirror drum (8) on to a translucent screen. Two lenses (9) forming enlarged images of the Kerr cells on the screen constitute a projector combination, and are placed for convenience in the incident and reflected beams. In order to use the necessarily limited apertures of the mirrors efficiently, the axes of the five pencils of light converge towards a centre situated approximately at the surface of the mirror drum. The double prism system is included in order that the directions of the beams may be individually adjustable, and the Kerr-cell assembly is movable to and from the mirror drum for focusing purposes.

The mirror drum is rotated by the synchronous motor (10) through the 2 : 1 right-angle spiral reduction gearing (11). The latter has provision for moving one gear longitudinally with respect to its axis, thereby altering the phase relationship of the driving and driven shafts, an adjustment which provides for correct framing of the receiver. A damped spring-coupling (12) of similar construction to that of the transmitter is inserted between the driving mechanism and the mirror drum in order to smooth out irregularities arising from non-uniformity of motion of the driving motor and from imperfectly-cut gears.

In cases where it is impossible to take advantage of a.c. supply mains for providing synchronous motion of the receiver with the transmitter, a phonic motor (13) integral with the mirror drum may be used. This motor is designed to operate from the 1 250-cycle signals generated at the transmitter, after sufficient amplification. Its large diameter provides for a large moment about its axis and is sufficient to hold a local series wound d.c. motor connected to its shaft revolving at the correct speed, and also to maintain a definite orientation of the receiver mirror-drum with respect to the transmitter scanning apparatus.

Receiver Amplifiers.

The potential received from each of the transmission channels is of the order of 6 volts, corresponding to full picture modulation. A further amplification of roughly 100 times is necessary before the signals may be impressed upon the Kerr cells. Fig. 8 shows the circuit of the receiver amplifiers, in which it becomes necessary to include transformers. These have hitherto been intentionally avoided on account of the phase distortion they are liable to introduce. If a transformer is not employed it is necessary to resort to large valves, which render the equipment unduly costly.

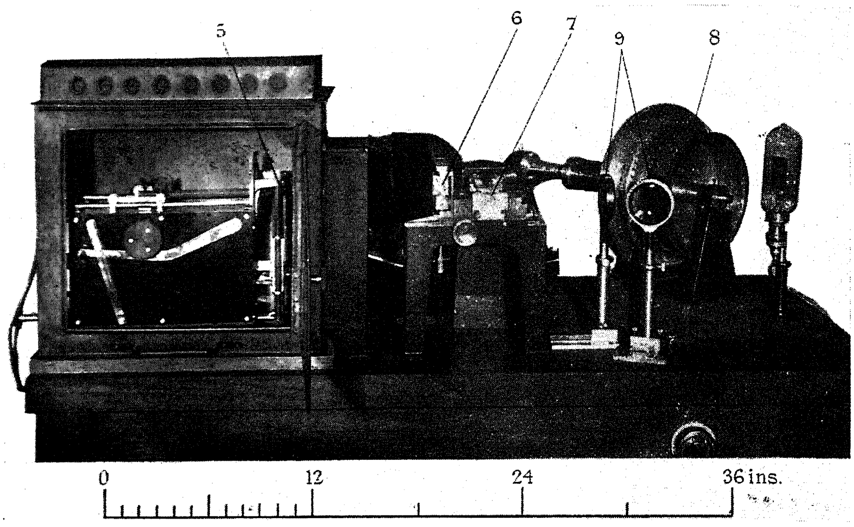

FIG. 5.—Receiver.

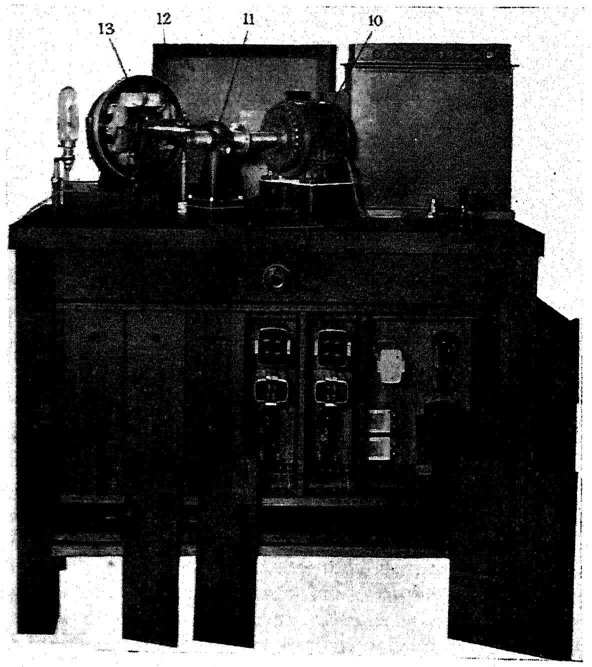

FIG. 6.—Receiver.

THE KERR CELLS.*

In the design of the Kerr cells a number of points had to be observed. First, it was desirable that the cells should operate with comparatively low voltages and thus require modulating amplifiers capable of handling comparatively low voltage-swings; also with a sufficiently low steady voltage applied across the cells there is no fear of electrical breakdown in the nitro-benzine. Secondly, it is necessary to condense light on to each cell in order to obtain sufficient light on the receiver screen, and in consequence the electrodes have to be shaped to accommodate the converging beam.

The intensity (I) of the monochromatic light transmitted by a Kerr cell is given by the equation*

$$I = a^2 \sin^2\left\{\tfrac{1}{2}Kl(E/d)^2\right\} \quad . \quad . \quad . \quad (1)$$

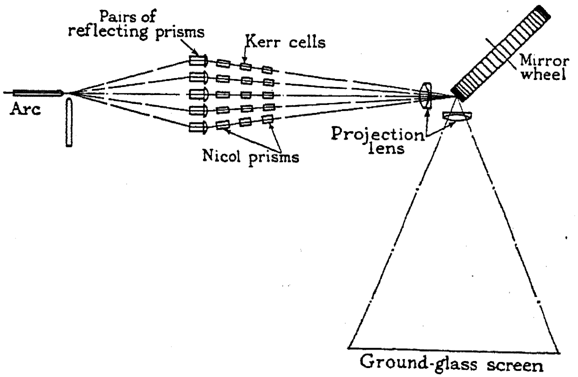

FIG. 7.—Receiver optical system.

where a = maximum amplitude;

K = a constant depending upon the substance enclosed in the cell and upon the wavelength of the light traversing it;

l = length of effective light-path in the electric field;

E = e.m.f. (volts) applied across the electrodes;

and d = separation distance of the electrodes.

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* J. KERR: *Philosophical Magazine*, 1875, vol. 1, p. 337.

* See "Kerr Cell Method of Recording Sound," *Transactions of the Society of Motion Picture Engineers*, 1928, vol. 12, p. 748.

In order that E should not be excessive, l should clearly be as large and d as small as possible. On the other hand, the light absorption of the nitro-benzene is proportional to l. In addition, both these dimensions determine the effective optical aperture of the cell, and their specific values were so chosen that optimum light at a given safe potential was obtained.

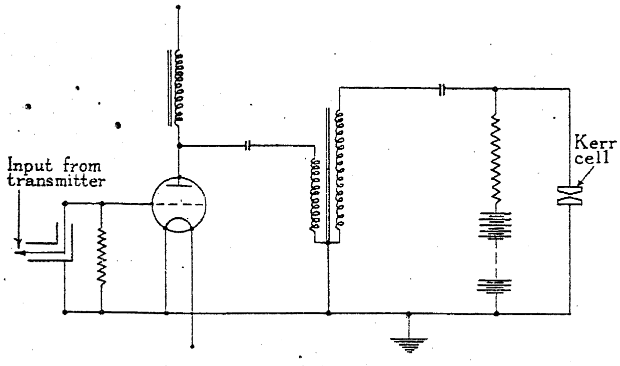

FIG. 8.—Receiving amplifier.

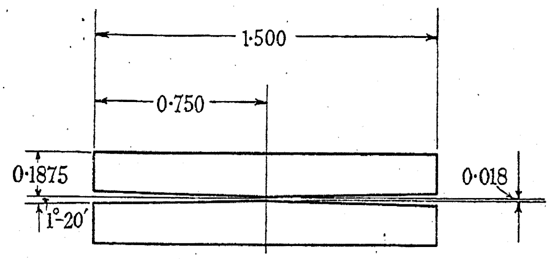

FIG. 9.—Kerr-cell electrodes (dimensions in inches).

Fig. 9 shows the shape and dimensions of the Kerr-cell electrodes. These were constructed of brass, which was subsequently platinized in order to prevent tarnishing. The cells require a steady biasing potential of about 800 volts, superimposed upon which are the picture signals having a double amplitude of 600 volts for maximum modulation. The cells will, however, stand an overload of 100 per cent of the signal amplitude without electrical breakdown.

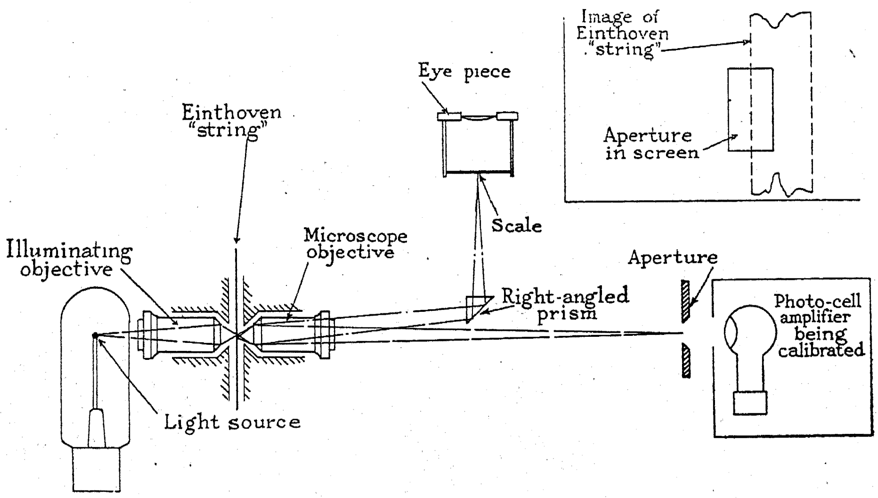

FIG. 10.—Method for optical calibration of amplifiers.

CALIBRATION OF THE SYSTEM.

In order to give the results obtained with the equipment their full significance, it is necessary to know precisely the conditions prevailing in the various components of the system when those results were obtained.

First, the amplifiers—including the photo-electric cell and the transmission and receiving amplifiers—were calibrated. In the case of the transmitter both banks of amplifiers were calibrated together. In order that a true frequency characteristic, approximating as nearly as possible to working conditions, may be obtained, it is necessary to inject into the cell light modulated at various frequencies and having a constant amplitude, and to measure the corresponding voltages generated at the output of the amplifier.

Fig. 10 shows the method of calibration used. An image of a stretched duralumin ribbon, constituting the "string" of an Einthoven galvanometer, was formed by means of a microscope objective on a screen containing a rectangular aperture. The image was arranged to overlap the latter, as indicated in the inset diagram. When the ribbon is set in vibration by passing an alternating current of any particular frequency through it, the amount of light transmitted through the aperture in the screen is modulated at that frequency. Moreover, the amplitude of vibration of the ribbon can be observed with an eye-piece, and therefore the amplitude of the light transmitted can be adjusted to any predetermined value by a simple measurement on a scale. The frequency range obtainable by this method is that of the galvanometer, which extends up to 20 000 cycles per second. A modulated neon lamp connected in the anode circuit of a valve was used to calibrate the remaining portion of the frequency characteristic demanded from the amplifiers. The frequency response of the lamp was obtained up to 20 000 cycles per second by calibrating a photo-cell amplifier first by the method described above, and then by means of the lamp, assuming that the alternating component of the emitted light was proportional to the alternating voltage applied to the grid of the valve. The discrepancy between the two calibrations is the frequency characteristic of the neon lamp and valve circuit, and this derived characteristic was assumed to continue over the remainder of the frequency range to 25 000 cycles per second.

The amplification of the photo-cell and transmission amplifiers of each channel, and also of the tuned networks which boost the upper frequencies, were adjusted so that the frequency characteristics of each channel to the end of the transmitter were practically identical, as shown in Fig. 11, curve (*a*).

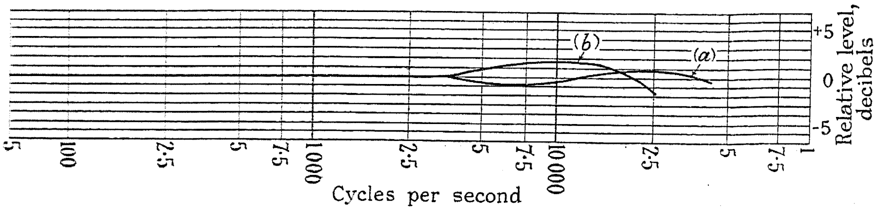

FIG. 11.

(*a*) Frequency response of transmitter alone. (*b*) Frequency response of complete system.

The problem of calibrating the receiving amplifiers and Kerr cells is not difficult. The transmitter and receiver amplifying systems were brought together and the light from a particular Kerr cell was arranged to fall into the photo-electric cell in its channel at the transmitter. The transmission lines were then removed from the output of the transmitter, and voltages of various frequencies and of constant amplitude were applied to the ends of the lines, while the corresponding potentials were measured across the output of the transmitter. In this way the characteristics of each channel were obtained under working conditions, and the values of the components constituting the second resonant compensating network were adjusted until the output from the Kerr cells was uniform for constant input to the photo-electric cells over the required frequency range. Curve (*b*) shows the results of this calibration and is an indication of the total electrical frequency range which the television equipment, including photo-electric and Kerr cells, is capable of handling. Subsequently, the response at the upper frequencies was increased in order to compensate for optical losses due to the finite size of the scanning apertures.

DISTORTION OF THE RECEIVED PICTURE.

The received picture may contain the following kinds of distortion:

(*a*) Geometric distortion, due to defects in the transmitter and receiver optical systems which give rise to erroneous positions of picture elements with respect to the boundaries of the received image.

(*b*) Non-linear electrical distortion, due to working over non-linear portions of the characteristics of components such as the valves or Kerr cells. With the latter must be associated chromatic distortion.

(*c*) Frequency distortion, which produces either deficient or accentuated definition at particular parts of the picture, and may introduce non-linear distortion.

(*d*) Phase distortion, which gives rise to fictitious positions of picture elements upon the receiver screen.

Geometric Distortion.

If the scanning lenses at the transmitter moved along a path parallel to the plane of the film in the projector gate a parallel undistorted image would be swept over the photo-electric cell apertures, but in practice these lenses move along an arc of a circle of radius equal to that of the lens drum. The image of the rectangular frame of the gate shown [Fig. 12(*a*)] by the dotted outline in its correct position on the receiver screen is consequently distorted into the shape shown in the full outline.

Owing to imperfections in the receiver optical system the image of a rectangular aperture formed by the mirror drum is distorted into the shape shown in Fig. 12(*b*). The image is distorted in three ways: first, the scanning lines (running vertically) are bowed as indicated; secondly, the distance traversed by a scanning spot at the convex end of the image per element of rotation of the mirror drum is smaller than that traversed by a spot at the concave end, i.e. the picture is slightly tapered from left to right; thirdly, this tapering, besides being present over the whole received image, affects the formation of the section of the image corresponding to each channel, and as a result a straight line at the transmitter includes a number of steps at the receiver.

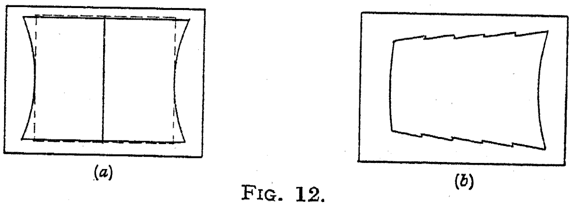
(*a*) (*b*)

FIG. 12.

(*a*) Distortion of picture due to lens drum at transmitter.
(*b*) Distortion of received image due to mirror drum.

It may be noticed that on one side of the picture the "bowed" distortions due to the transmitter and the receiver optical systems are in opposite directions, and therefore the resultant distortion of the received image on this side will be neutralized to a small extent, while at the other end it will be augmented. However, the maximum bowed distortion produced at the transmitter amounts to only 1·3 per cent, while that at the receiver is 8 per cent; thus the neutralizing effect will be inappreciable.

The truncated appearance of the received picture can be removed to some extent by inclining the screen slightly to the mean incidence of the scanning beams, thus increasing the distance traversed by a scanning spot at one end of the picture and correspondingly decreasing the path at the other end. The only satisfactory method of eliminating geometric distortion is to arrange that each scanning spot at the transmitter follows a path similar to that of the corresponding spot at the receiver. Similar optical systems should therefore be included at both stations. The errors in scanning at the receiver will not be removed in this way, but similar errors will be introduced at the transmitter which will give the picture elements their correct position relative to the boundaries of the received image. The truncated appearance of the frame of the received image will also be present, but this can be removed—at the expense of the edges of the picture—by placing a rectangular mask around the receiver screen. Part of the truncated appearance may, of course, be removed by inclining the receiver screen, but a similar inclination should also be given to the transmitter photo-cell screen.

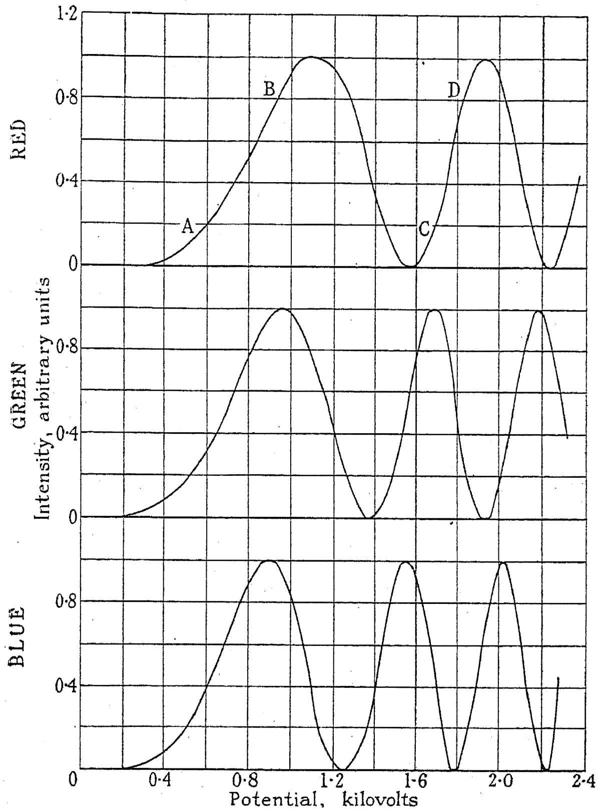

FIG. 13.—Kerr-cell characteristic curves.

Following this policy, the transmitter optical system was modified as in Fig. 2(*b*), in which a mirror drum is included. As a result geometric distortion was practically removed from the received picture.

Non-Linear Electrical Distortion.

Serious non-linear electrical distortion may be introduced at each valve in the amplifying system, at the transformers, and also at the Kerr cells. In this system the amplifiers were so designed that overloading occurs at the Kerr cells before it occurs at the valves, or before saturation takes place at the receiver-amplifier transformers. These results are therefore limited to the effects of overloading the Kerr cells.

The curves in Fig. 13 show the relation between the intensities of red, green, and blue light transmitted by a Kerr cell and the potential applied across its plates, as calculated from equation (1) on page 344.

In order to accommodate sufficiently large changes in light intensity it is necessary to work over an extended portion of the curve AB, which necessitates introducing some distortion. This distortion is not serious and apparently has no detrimental effect upon the picture, but if it is carried to excess chromatic distortion is introduced.

Chromatic Distortion of Kerr Cells.

It will be seen that up to a potential of 950 volts the curves are very similar, but the intensity of the blue reaches a maximum before the red, and in the neighbourhood of a potential of 1 100 volts there remains an excess of red light. This form of distortion shows up as areas of red light, which are particularly noticeable on the grey-green background produced by the colour of the nitro-benzene. It was found preferable, especially when a large amount of compensation for frequencies in the neighbourhood of 20 000 was included, to under-bias the cells so that non-linear Kerr-cell distortion was introduced due to the bottom bend of the intensity/potential curve, with a corresponding reduction of chromatic distortion.

The intervals between successive maxima and minima of the intensity/potential relation become progressively smaller as indicated in Fig. 13, and it would be possible to work over the portion CD with a greatly reduced amplitude of the picture signals by increasing the biasing potential to 1 750 volts. It would be necessary in this case, however, to use monochromatic illumination, since at this potential the intensity curves for various colours are widely different. As the source of illumination must be particularly intense, the excessive chromatic distortion introduced by the Kerr cells working under these conditions renders this method of reducing the amplitude of modulation almost impracticable.

Frequency Distortion.

Thus far compensation for attenuation of the upper frequencies in the transmitting and receiving systems had been included in the amplifiers, but further attenuation still remained, due to the finite size of the scanning spots. The amount of this loss, at a particular frequency, is a matter of simple calculation, and the loss may be compensated for by increasing the magnification of the amplifiers where it occurs.

Suppose that the image traversing the photo-cell apertures at the transmitter is composed of light and shade varying sinusoidally along the length of the scanning lines with maximum amplitude; the distance λ between successive maxima (i.e. the wavelength) being v/n, where n is the frequency at which the waves pass a fixed point on the screen when the image is travelling with velocity v.

First, consider the case where such an image is swept across a rectangular aperture having unit length and infinitesimal width equal to ds. The amplitude dA of the light penetrating this aperture may be represented by

$$a\,(\cos ws + 1)\,ds$$

where a = mean illumination per unit area;
s = co-ordinate measured along the scanning lines;
and $w = 2\pi n/v$.

With a photo-cell aperture of finite width d, the resultant illumination penetrating the aperture is that produced by superimposing the effect of infinitesimal apertures extending from $(s - \frac{1}{2}d)$ to $(s + \frac{1}{2}d)$. Thus the resultant illumination is given by

$$A = a\int_{s-\frac{1}{2}d}^{s+\frac{1}{2}d} (\cos ws + 1)ds$$

$$= 2a\frac{1}{w}\cos ws \sin\left(\tfrac{1}{2}wd\right) + ad$$

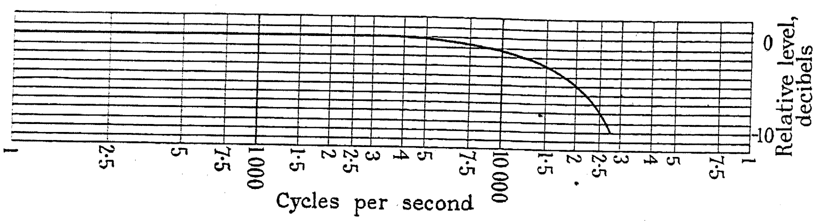

FIG. 14.—Attenuation due to finite scanning apertures.

Comparing this with the case of an infinitely narrow aperture, the depth of modulation of the transmitted light will be reduced in the ratio

$$\frac{2a\sin\left(\frac{1}{2}wd\right)}{awd} = \frac{\sin\left(\frac{1}{2}wd\right)}{\frac{1}{2}wd} = \frac{\sin\left(\pi nd/v\right)}{\pi nd/v}$$

The same reduction will also be experienced at the receiver, where wd is designed to be the same as that at the transmitter. The total effective amplitude as observed upon the receiver screen will, therefore, be $\left[\frac{\sin(\pi nd/v)}{\pi nd/v}\right]^2$ times the original amplitude of the image being scanned at the transmitter.

The amount of this loss at various frequencies is given in Fig. 14, which shows that compensation for a deficiency of 7·5 decibels of response at 23 400 cycles per second should be included. This deficiency was compensated for by further adjustment to the resonant networks, which resulted in an appreciable improvement in the definition of sharp edges. When this compensation was carried to excess, chromatic distortion, characteristic of Kerr-cell overloading, was introduced if frequencies corresponding to the limit of resolution of the system were excited.

High-Frequency Limit.—The effect of lowering the upper frequency cut-off was noted, in order to ascertain whether it is necessary to provide such an extended frequency range for the formation of good television images, and it was found that the picture improved in definition continuously as the electrical cut-off approached the optical cut-off of the system. No results were obtained with the electrical cut-off extending beyond this limit, but it is anticipated that the definition would continue to improve, provided that no non-linear distortion was introduced.

Low-Frequency Limit.—The highest possible low-frequency cut-off obtainable without detriment to the received picture was also estimated by including filters to remove all frequencies below definite limits. All frequencies below 200 were first removed, with the result that extensive dark areas scanned at the transmitter were reproduced at the receiver as illuminated areas, only their outlines remaining dark. This cut-off frequency had to be lowered to 20 before the distortion due to this cause could be considered negligible. By altering the magnification of the scanning images at the transmitter, thereby providing a dark space between successive images, pulses could be propagated in the picture channels at a frequency of 12½ pictures per second multiplied by 30 lines per picture, or 375 cycles per second, and therefore the lower frequency limit could be raised to some extent. Actually, this method was not used, since pulses of this nature are large compared with the picture signals and are sufficient to overload the Kerr cells seriously.

Since the amplifiers are not capable of amplifying at zero frequency, the mean intensity of the received picture is constant and independent of the mean intensity of picture to be transmitted. No satisfactory method of overcoming this form of frequency distortion has been found, so that the choice of pictures which are suitable for transmission is limited to those having a definite average density.

Phase Distortion.

As mentioned previously, the presence of phase distortion is shown by fictitious positions of picture elements. The size of a scanning spot is hypothetically the limit of resolution at the receiver screen, and it was therefore assumed that any picture element might be displaced by the width of a scanning spot from its correct position without serious detriment to the received image. Thus at the frequency (23 400) corresponding to maximum definition, a discrepancy in phase of 180° from that corresponding to constant time-delay with frequency is permissible. At another frequency (n) the error allowable is proportional and is equal to $\pi n/23\,400$ radians.

The effect of phase distortion is definitely noticeable on the received picture, and is largely due to the frequency-response correcting networks; it appears most prominent when frequencies between 1 000 and 10 000 are excited. Actually, phase-distortion measurements have only been made on the components of the picture channels, and the results obtained tend to show that the limits defined above are materially exceeded. Before any phase measurements and results obtained upon the receiver screen can be correlated, it appears that it will be necessary to devise a similar method to that used for obtaining the frequency responses of the amplifiers, which will enable the phase difference at a given frequency between the light input to the photo-electric cells and the light output from the Kerr cells to be measured.

SYNCHRONIZING.

Under the conditions in which the apparatus has been used a 3-phase supply is available for synchronizing the transmitter with the receiver, and no difficulty has been experienced in this connection.

Synchronizing by means of the 1 250-cycle signals is satisfactory, although hunting between adjacent poles of the phonic motor caused some difficulty. This was due to the presence of backlash in the reduction gearing, but would otherwise have been removed by the damping of the spring coupling. An effective remedy was to mount the d.c. motor directly upon the mirror-drum shaft and to provide the former with an auxiliary flywheel.

MECHANICAL FILTERS.

The effect was observed of short-circuiting the mechanical filters, which immediately produced considerable unsteadiness in the received picture. In some cases, particularly in that of phonic-motor synchronizing, it was noted that the filtering system used was inadequate, and could have been improved by including a further section consisting of a damped spring-coupling and a flywheel between the driving motor and the existing spring-coupling.

CONCLUSIONS.

Although it is difficult to stipulate the number of picture points which should be provided in order to compose a good television image, the 15 000 points provided in the system described were sufficient to show details of a moderately pronounced character as contained on average cinematograph photographs. Whereas sub-titles were resolvable, some smaller details were definitely rather obscure. The method of limiting the field comprised in each photograph and scanning only the centre of attraction was ruled out on account of the loss of interest which would thereby be introduced.

Further, any attenuation in the transmission or receiving system at the higher frequencies which would cause the system to cut off below the scanning limit of resolution has a detrimental effect upon the received picture. This effect is not pronounced in cases where the original picture is devoid of small detail.

The arc and Kerr-cell receiving system satisfactorily illuminates by transmission a ground-glass screen measuring 24 in. by 16 in., although if desired these dimensions may be increased—with a corresponding decrease in the brilliance of the received image.

Comparatively small amounts of distortion only are permissible in the Kerr cells, since this distortion is characterized by a change in colour in parts of the received picture where the distortion takes place, rather than by erroneous degrees of shade.

The scanning speed of $12\frac{1}{2}$ pictures per second is insufficient, the large received picture augmenting the effect of the flicker at this speed.

Very steady pictures are obtained using 50-cycle 3-phase mains as a synchronizing medium, provided that mechanical filters are included between the scanning apparatus and the driving mechanism. In cases where synchronized mains are not available and a phonic motor is used, damped mechanical filters containing two sections appear to be necessary.

The author wishes to express his indebtedness to the Gramophone Co., Ltd., for permission to publish this paper on results obtained in their laboratories.

DISCUSSION BEFORE THE WIRELESS SECTION, 5TH JANUARY, 1932.

Mr. H. M. Dowsett: I am particularly interested in the application of Kerr cells to television, and I note that the author projects the image of a Kerr cell on to the screen and so is able to dispense with a subsidiary lens aperture. As regards the limitations which he sets to the use of Kerr cells, he points out that in order to keep down the voltage on the electrodes and so simplify the amplifier problem the distance d between them has to be kept as small as possible, and in order to make the cell function to the best possible advantage the length l has to be made as large as possible. As a result he employs a gap between the electrodes of 0·018 in. (equivalent to 0·45 mm) and consequently has to use a biased voltage of about 800 volts, the maximum voltage being 1 100, and the breakdown voltage about double this value. With five such Kerr cells he is able to provide sufficient illumination for a screen of approximate dimensions 2 ft. × 1 ft. 4 in., which is rather larger than what is required for home use yet too small for projection to a large audience. (The cost of the apparatus would prohibit it from being used in the home.) To provide sufficient illumination for a screen of reasonable size one would have to increase the voltage on the Kerr cells, which would themselves constitute rather a difficult problem under these conditions. The Marconi facsimile apparatus used to employ a Kerr cell with a gap of about 0·25 mm, and the voltage applied was of the order of 1 000 volts. To illuminate a screen about 6 ft. × 4 ft. one would require 9 times the amount of light which is being used on the author's apparatus; if the whole of that beam had to be passed through one Kerr-cell assembly the latter would have to be able to handle about 45 times its present light output. We are investigating this problem, and it may be of interest to give the constants of such a Kerr cell. We are employing a gap between the electrodes of something like 1·1 mm, and the biased voltage is of the order of 2 400 volts. The maximum voltage on the cell is about 3 800 volts, and the breakdown voltage on the nitro-benzene is of the order of 4 500 volts. I mention this in order to indicate that we have to consider using much higher voltages on the Kerr cell than those now being dealt with, and the amplifiers will have to be designed accordingly. The author reminds us that "the only satisfactory method of eliminating geometric distortion is to arrange that each scanning spot at the transmitter follows a path similar to that of the corresponding spot at the receiver." It has been suggested to me that although in this country, for instance, the transmitter scanning is done by means of a disc, there is no reason why one should not employ one of the newer types of cathode-ray scanning at the receiver. While there may be some advantage in employing a cathode-ray beam, which does not involve the inertia troubles often associated with a disc, at the same time the scanning of the cathode-ray-receiver tube is entirely different from that of the disc transmitter. Geometric distortion is therefore bound to be introduced, and this might reasonably be expected to upset the good properties of the cathode-ray tube. When a cathode-ray transmitter is available, no doubt the cathode-ray-tube receiver will be used in conjunction with it. There is another method of avoiding distortion to which I will refer. In the author's apparatus there are five channels, and the picture is cut up into five sections. At the receiver there is the difficulty of satisfactorily aligning these five sections, and there is also the difficulty of matching the five channels so that the signal intensity/frequency characteristics are the same. One of the troubles met with in this connection is that the changing of a valve may mean that one of the channels has to be rebalanced. I think that the following method would do away with these difficulties, while still making use of five channels. I suggest that instead of sweeping one-fifth of the picture over each photo cell the lens should sweep the whole picture over the five photo cells, so that the picture would be sent along each channel with a phase difference of one-fifth of the total time. Then at the receiving end the five Kerr cells would function as before, but each one would have to project on to a separate mirror wheel, which would superimpose its own complete picture on the complete pictures transmitted and projected by the other mirror wheels. Even if the channels became unbalanced under certain conditions, it would not be noticeable in the final picture.

Mr. W. D. Wright: The method by which the author calculates the attenuation due to the finite aperture of the scanning spot is of great value. Hitherto there has been much confusion of thought as to the connection between size of scanning spot, amount of detail in received image, frequency band, and the dot analogy of newspaper photographs. It should now be clear that the detail transmitted and received depends solely on the frequency characteristic of the system, provided that this includes the attenuation due to the size of the scanning aperture. The reduction factor given by the author, namely

$$\left[\frac{\sin(\pi n d/v)}{\pi n d/v}\right]^2$$

can be readily modified to the slightly different form

$$\left[\frac{pN}{n\pi}\sin\left(\frac{n\pi}{pN}\right)\right]^2$$

where p is the ratio of the whole scanning area to the area of the scanning spot, or what has previously been called the "number of picture elements," and N is the number of times the whole picture is scanned per second. This expression is somewhat more convenient for general use, and it enables a family of curves to be drawn quite rapidly to show the attenuation at various frequencies for different values of p and N. Such a set of curves is of fundamental importance in designing a practical television system if full use is to be made of a given frequency band. Any commercial system must have some upper frequency limit, presumably determined by the broadcast band available, and it should be the aim in the design to produce a flat characteristic up to that limit. Whether this result is obtained by increasing the magnification of the amplifiers to compensate for the scanning-spot attenuation, or by using a sufficiently small spot (large value of p) to make the attenuation negligible, is a matter for the designer. What should be abundantly clear, however, is that the size of scanning spot has only a very remote connection with the so-called "number of picture elements." The factor controlling that quantity, in so far as it exists, is the upper frequency limit that is transmitted. The above discussion takes no account of the author's suggestion that the resolving power of the eye should be used to determine the maximum frequency required. This suggestion seems to be unsound, for several reasons. In the first place, it makes the frequency range dependent on the position of the observer, usually an unknown quantity. Secondly, in the present stage of development the detail obtainable is relatively meagre, so that to observe the screen from a distance where a scanning spot subtends less than the angular resolving power of the eye, usually less than 1 minute of arc and sometimes only 10 seconds of arc, would make the picture appear very small. Thirdly, a small picture may quickly fatigue the eye owing to the steady fixation of the eye muscles that is required in order to view the image continuously.

Mr. C. G. Mayer: I should be glad if the author would give a few more details regarding the way in which he calibrated the system.

Mr. R. A. Watson Watt: I am in some doubt as to the author's remarks regarding "the practical limitations imposed by the very limited frequency band it is possible to transmit along one channel"; I do not know whether he refers to real physical limitations or to the awkward "administrative" limitations which are bound to arise in the application of television to radio channels. While I recognize the great importance of his arguments in relation to line television, I have no doubt that the majority of people are waiting much more anxiously for radio television in the home than for line television, and I should like to ask the author whether he considers that the difficulties of operating one single wide radio channel of a total band width N are as great as or greater than those of operating a number of discrete channels in which the sum of the band widths is equal to N. I have in mind the fact that multi-channel working must necessarily be spread more widely through the radio-frequency spectrum than single-channel working of the same effective band width, if only because of the finite steepness of filter "walls." I feel that this inevitable spread to more widely-separated limiting frequencies makes the multi-channel system more vulnerable to defects of propagation—differential fading and the like. This may be a very high price to pay for the reduction of some, though by no means all, of the difficulties in the terminal apparatus.

Mr. C. E. G. Bailey: Among the problems which the author has successfully faced and overcome, not the least is that of producing an amplifier with a magnification of 120 decibels having a substantially flat characteristic between 25 and 25 000 cycles per second. The paper hints that some definite limitations are being reached in practical amplifier circuits at the upper frequencies, and that these are being partly overcome by resonating with tuned circuits. The difficulty of phase displacement mentioned by the author may be a severe one. The phase rapidly changes with frequency from lagging to leading, an effect which materially rounds the front of a square-fronted wave; this effect appears at the upper frequencies which the author seeks to emphasize. If these difficulties are found to be still pronounced when the author attempts to include even higher frequency bands, a band amplifier might very well be constructed which would pass from, say, 1 000 to 1 025 instead of from zero to 25 kilocycles per second. The former would probably be much the less difficult achievement. The final rectification of the high-frequency currents might take place either in the last stage of the amplifier or possibly even in the Kerr cell itself. Since the latter has an approximately bi-quadratic law, it would rectify and de-modulate a high-frequency signal. This leads to other interesting possibilities such as the use of a solution in nitro-benzene of one or more bi-polar substances, which are known to resonate at the higher frequencies and to give a very much increased Kerr effect. This phenomenon is probably due to an actual rotation of the molecule at a frequency of the order of 10 to 20 megacycles per second. The resonant effect, if sufficiently broad, might be used to increase the amplification of the Kerr cell in the final stage.

Dr. L. E. C. Hughes: Apart from the technical interest involved in solving the problems associated with television, I wish to raise the question of its adoption on a large scale. First, there is the possibility of relaying to a number of auditoriums analogous to cinemas. Screen technique in editing the sound and scene must of necessity be employed, automatically eliminating spontaneity. The material used for television must therefore be recorded, preferably on film. The raw material—the film—is therefore common to both television and the cinema, with deterioration due to reproduction in the former. The production of sound film is expensive (minimum cost about £3 per foot for drama), whereas the manufacture of prints is particularly cheap (less than 1d. per foot), and the cost of their distribution more so. We have then to consider the relative cost of distributing film and distributing television over expensive channels of sufficient quality to compete against the technically exquisite results now obtainable on the screen of any cinema. There is, of course, no difficulty in connection with the accompanying sound channel. Coupled with the relative inflexibility of television, the cost of distribution of a perfected television system is likely to be prohibitive, unless something akin to a micro-ray channel is used. Secondly, a broadcast domestic television service would be in competition with sub-standard film, and similar principles apply, except that the user has a wider and more flexible choice of material from the film library. At present most of the material obtainable from the libraries is several years out of date, and if this objection can be economically removed without injuring the public cinemas the chief claim for television in the home will be challenged. The greater entertainment value of television in comparison with the cinema is instantaneous reproduction, which biases its claims to topical events. The demand for facts is adequately met by the Press and broadcasting; the great majority of people are not available to "look in" when particular events take place. Interesting events from the screen point of view are normally available after a few days in many cinemas, but there is no difficulty in flooding the country with films within 24 hours. Sound films are very popular with the public because they keep two senses fully employed. Music is employed with "silent" films to prevent distraction via the aural sense. Perhaps television is to become the key to a higher standard of broadcast listening by giving the eye something to look at, thus eliminating visual distraction.

Mr. T. Wadsworth: When the layman thinks of television he unconsciously assumes a radio link between the receiver and the transmitter; the author eliminates all the difficulties of this radio link by using land lines to connect the receiver and transmitter. It is stated on page 340 that the investigation was carried out in order to investigate the problems associated with the transmitter and receiver, and to obtain information regarding the amplifiers, photo-electric and Kerr cells, and the optical conditions necessary to secure good results. This being so, the system can have no direct application to the broadcast band (250 to 2 000 m), because of the 9 kilocycles per second separation required by international agreement. Furthermore, if transmission on an 8-m to 10-m carrier wave were contemplated, the 20-kilocycle modulation at this carrier frequency would give rise to (*a*) limited range, and (*b*) technical difficulties in radiating and receiving the 8-m carrier wave modulated at 20 kilocycles per second. As the system described is not suitable either for radio transmission or for land-line transmission, one is forced to ask why the investigation described in the paper was carried out. Knowing that it has been proposed to utilize a central cinema theatre fitted with a television equipment, and to transmit from this either by short-wave radio or by short land-line to other cinemas in the immediate neighbourhood fitted with the necessary receiving apparatus, one is inclined to ask whether the author had such a scheme in mind when he undertook this work. By this means one could show current news items, topical events, etc., using only one film. On page 342 the author refers to the attenuation of the gas-filled photo-electric cell at the high frequencies used. I should like to ask whether he could give us some information as to the actual attenuation at these frequencies, due to the self-capacitance of the leads of the photo-electric cells. As regards the statement on page 348 that the amplifiers are not capable of amplifying at zero frequency and that no satisfactory method of overcoming the frequency distortion has been found, there may, of course, be more in this statement than is apparent, but would not a d.c. amplifier, which does amplify at zero frequency, be a satisfactory solution of this problem? On page 349 the author suggests that he was not quite satisfied with the picture obtained when using 15 000 picture points. Surely it is known how many picture points are necessary to give a good reproduction; I should like to ask the author whether he could give us this information.

Mr. A. S. Radford: I should like to know what degree of accuracy is required in setting up either a mirror drum or a lens drum, in order to eliminate distortion. It seems to me that from the signal point of view, provided the receiver and transmitter can work more or less in synchronism, it is not essential to have a regular phase displacement around the drum. I should like to have the author's opinion on this point. With regard to multi-channel systems in general, it would appear that distortion in the image occurs at the edges of each section of the picture, i.e. at discrete points across the picture, so that a fair amount of distortion is liable to occur at the centre of interest of the received picture. Does Mr. Dowsett's suggestion overcome this difficulty?

Mr. R. V. Ripley: I am particularly interested in the paper because it gives definite methods of measurement and the results of such measurement. It is, of course, only through measurement that we can make progress with television. In the calibration of the system a neon lamp and valve combination was used, and I think that the paper might well have included an indication of the characteristic of this combination. At the recent discussion before this Section on "Technical Problems in connection with Television"* a great deal of attention was given to the problem of the frequency necessary to cover a definite number of picture points. The present paper leaves no possibility of doubt on this question. A better term might, however, be found to replace "picture point." This term has been used by analogy with newspaper reproduction, whereas the television system described in the paper can be compared with newspaper reproduction only as regards the number of scanning lines. Along the scanning lines the point analogy is no longer valid, as we are dealing with an effect such as is obtained with an ordinary direct photographic print—it is a modulation, not a series of points.

Col. A. S. Angwin: It has been suggested that if for a predetermined number of scanning lines per inch, the expedient were adopted of scanning alternately the odd and the even numbers of these lines, given the same frequency one would obtain either a rather better degree of definition or, alternatively, the same quality of definition with a smaller frequency band. It seems to me that when using cinematograph film that suggestion might very likely prove to be correct; if alternate strips were scanned in succession the natural tendency of the eye to fill in the blanks would give on the whole a greater clearness of picture. Whether this would be equally true when televising a quickly-moving object, where the movements are in both directions across the picture, seems to me rather doubtful. I should like to know whether the author has any information regarding that suggestion, and whether it is likely to be of practical utility from the point of view of economy in band width.

Mr. C. O. Browne (*in reply*): Before replying to those questions which are of a more technical nature, I wish to remove a tendency, which still persists, to compare the results obtained with this system of multi-channel television with a cinema reproduction, without due regard being paid to the processes which the picture elements produced at the transmitter have undergone before the final recomposition of the image upon the receiver screen. Perhaps the unusual size and detail of the received image is some justification of this. When the system was originally designed there was no intention that such a comparison should be made, but it was intended as a means for the scientific examination of the terminal conditions necessary in order that good results should be obtained. There is no question at present of a large-scale television system competing with the results obtained in a cinema, as mentioned by Dr. Hughes.

I appreciate the advantage of the method of scanning outlined by Mr. Dowsett, but there would be considerable difficulty in carrying out the system in practice with the 5-channel apparatus described in the paper. The mirrors on the scanning drums at both the transmitter and the receiver are so adjusted that the distance between the first and last scanning lines amounts to only one-fifth of the width of the picture, which means that the difference in tilt of the first and last mirrors would be one-fifth of that necessary in the arrangement outlined by Mr. Dowsett. In consequence, the arrangement actually used reduces very considerably the optical and mechanical difficulties associated with the transmitter and the receiver, and also allows optical systems which are more "optically perfect" to be incorporated.

Contrary to Mr. Wright's remarks, I have not suggested that the resolving power of the eye should be used to determine the maximum frequency required, but I have suggested that the resolving power of the eye should be used to determine the optimum distance at which a given television image should be viewed. I have also suggested that the resolving power of the eye should be used as a basis for determining the maximum permissible phase distortion at any particular frequency. I have found empirically that, with the comparatively feeble illumination of a television image, the angular resolving power of an average eye amounts to 5 minutes of arc. Using this as a basis for calculation, the received image, measuring 24 in. by 16 in., should be viewed from a distance of 29 ft. I think it is not generally realized that, if it were viewed from this distance, the received picture should appear to be no more deficient in detail than the original cinema picture at the transmitter, providing, of course, that the system is operating perfectly.

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* *Journal I.E.E.*, 1931, vol. 69, p. 1232.

As I have not dealt in the paper with the question of transmitting multi-channel television by means of radio links, the limitations to which I have referred are purely physical and are introduced merely by the properties of the components comprised in the picture channels. There is no doubt that the transmission of television images in a number of channels would be more difficult than the transmission of the same images in a single channel, but this difficulty would be considerably offset by the advantages of the multi-channel system at the terminal apparatus.

Mr. Wadsworth's assertion that the system is unsuitable for transmission either by means of a radio or a line link appears to be unjustified, because no reasons have been given why 20-kilocycle modulation should limit the range of an 8-m to 10-m carrier, and I know of no reference to a difficulty of this nature; nor are the technical difficulties in radiating and receiving such a modulated wave by any means insuperable. The assertion that the system is unsuitable for land-line transmission is even more questionable, especially in the light of modern knowledge of multi-carrier transmission using a Franklin concentric feeder.

In connection with Mr. Wadsworth's remaining questions, the capacitance of the photo-cell leads, including all the stray capacitances of the input network to a photo-cell amplifier, amounts to 25 $\mu\mu$F, which represents an impedance of 360 000 ohms at 25 000 cycles per sec., and is effectively in shunt with a resistance of 300 000 ohms. Considering a photo-cell as a constant-current generator, the attenuation due to this stray capacitance at the upper frequency cut-off amounts to 5·5 decibels, which is considerably less than that actually experienced.

The use of a battery-coupled amplifier working in conjunction with a photo-cell is not very satisfactory, owing to the small amount of light input to the photo-cell and the consequently high amplification necessary, which renders this type of amplifier particularly unstable.

Until the subject which it is intended to reproduce is defined, it is impossible to determine the number of picture points which are necessary to give a good reproduction; the number of elements depends upon the amount of essential detail which it is desired to transmit.

The degree of accuracy with which a mirror or lens drum should be set up, mentioned by Mr. Radford, should be such that the scanning lines produced by the mirrors or lenses are in their correct positions to an accuracy of less than the width of a line. This stipulation presents no difficulty if due regard has been paid to the method of mounting each mirror or lens. Provided that the scanning device at the receiver scans the line corresponding to that being scanned at the transmitter, the lines may be scanned in any sequence. Tests have been made with this system on a number of irregular scanning sequences. In practically every case the illusion was produced of a number of lines which appeared to be moving slowly across the screen in a direction at right angles to the length of the scanning lines. This effect was so distracting that no better scanning sequence was found than that of a uniform progression across the picture. Apart from this defect, the scanning sequence outlined by Col. Angwin would have the advantages which he mentioned. Experiments have been made on this sequence with the object rather of reducing the flicker of the received picture than of reducing the frequency-band width necessary for its transmission.

Mr. Ripley asks for a calibration of the neon lamp and valve combination used, but this varies considerably throughout the life of the neon lamp. A number of lamps were found when new to have level characteristics over the required frequency range of the amplifiers, but subsequently they became deficient in response at the higher frequencies. It was necessary to re-calibrate the neon lamps before taking every response run on the amplifiers. There are no details which are not included in the paper of any practical interest in connection with the method of optical calibration of amplifiers, but I have described previously* a precisely similar method in connection with the calibration of talking-picture amplifiers, which may furnish Mr. Mayer with the information he is seeking.

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* "The Problem of Distortion in Sound Film Reproduction," *Experimental Wireless and The Wireless Engineer*, 1930, vol. 7, p. 71.

DISCUSSION ON

"AN INVESTIGATION OF PROBLEMS RELATING TO THE USE OF PIVOTS AND JEWELS IN INSTRUMENTS AND METERS." *

BEFORE THE METER AND INSTRUMENT SECTION, 4TH DECEMBER, 1931.

Mr. F. E. J. Ockenden: One of the outstanding results obtained by the author is the information as to the effect of loading on different cone angles, a question which he investigated with his projection apparatus. Some years ago when I was engaged in an investigation of a similar nature I adopted for loading purposes a device very like the author's, except that in some cases I used an apparatus which could be mounted in its entirety on the stage of a microscope. The loading chamber consisted of a graduated test-tube into which a fine stream of mercury could be run and a steadily increasing load thus applied to the pivot while the point itself was under observation. I was not at the time concerned with pivots having differing angles, since so far as the indicating-instrument designer is concerned the choice of angle is limited by the fact that his instruments have to work in both the vertical and the horizontal positions. The angle which long experience has shown to be most suitable for this purpose is 60°. I observed the disc which formed on the top of the pivot after the application of a given load by means of a metallurgical microscope, the diameter being estimated with the aid of a calibrated micrometer eyepiece. This method, while not perhaps as accurate as that adopted by the author, was extremely convenient and had the advantage that deformation of the pivot point into any form other than that of a circular flat was instantly noticeable. Provided that no appreciable "crumbling" of the material occurred, the method seemed to me to form an excellent basis for estimating the ultimate strength of the material used for the pivot. I am particularly interested in the effect of the amount of carbon in the steel used, and I have come to the conclusion that, as far as the ability of the pivot to resist undue loads is concerned, the proportion of carbon in the steel is the main consideration. The amount of carbon present in any plain carbon steel can be readily ascertained by taking a cross-section of a specimen of steel, which has been previously annealed, etching the section with a suitable reagent (such as dilute nitric acid), and then observing microscopically the resultant structure. This process is well known to metallurgists, and I have described it in a simple manner at a previous meeting of this Section.† It has the great advantage that extremely small specimens, weighing as little as 5 milligrams in some cases, can be investigated with considerable accuracy. Typical samples, similar to those which I will now project on the screen, are illustrated in the figures published in the report of the discussion referred to above. The importance of knowing the carbon content of a pivot steel is demonstrated by the graph shown in Fig. A, in which the abscissæ give the percentage carbon content and the ordinates the area of the disc formed on the various pivot points when a given constant load is applied. This latter quantity is, in fact, the reciprocal of the author's "strength per unit area." The area of the disc increases very rapidly with decrease in the percentage of carbon in the pivot. All the points on the curve are the mean results of not less than six different readings, none of which varied greatly from the mean. Although they were taken on a pivot having a fixed angle of 60°, similar results might reasonably be expected for pivots having other angles, the only difference being in the area of the disc formed. For these reasons I have become convinced that the only type of steel suitable for pivots is one containing a very high proportion of carbon. Such a material seems very difficult to obtain, due to the tendency to burn out the carbon surplus to 0·9 per cent during the process of drawing. Many specimens of steel wire were sent to me by manufacturers of repute which were said to have a carbon content of 1·2 per cent, but in fact the figure was much lower than this. The natural limit seems to be about 0·9 per cent, and it is of interest to notice that the "Stubs" steel used by the author for his experiments had a carbon content of 0·94 per cent. Had he used a steel containing a larger quantity of carbon, his results might have been considerably modified. It is also of interest to note that the stainless steel tested by him, which showed a strength per unit area much inferior to that of the Stubs steel, only contained about one-half the carbon content of the latter. I have mentioned at a recent discussion † before this Section the importance of carrying the hardening temperature used for the pivot sufficiently high to ensure that all the carbon is absorbed into solution by the steel and that none is left in the form

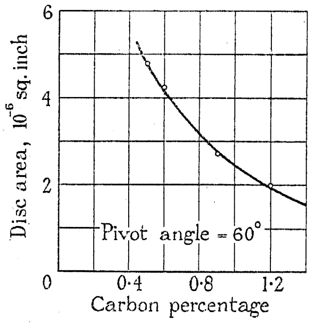

FIG. A.

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* Paper by Mr. V. STOTT (see vol. 69, p. 751).

† See *Journal I.E.E.*, 1929, vol. 67, p. 1160.

† See *Journal I.E.E.*, 1929, vol. 67, p. 1160.

lobular cementite when the hardening process is plete. Even a small proportion of free cementite have a profound effect on the wear occurring between pivot and the jewel surface, and I think that the ts set out in Table 4 would have additional value if were accompanied by some description of the nature he pivot surface as determined by microscopic stigation. The author describes some interesting riments on the effect on the tendency to wear of orientation of the basal plane of the natural stone reference to the tangent plane to the base of the The relative positions of these planes cannot be mined in the ordinary way by inspection of the ed article, and I understand that the author has X-ray analysis for the determination. I have for time past advocated* the use of polarized light for purpose; it has the advantage that the apparatus red is inexpensive and the results can be readily preted after a little experience. If all jewels going service were examined in this manner and the ts filed for future reference, I have no doubt that ble information would be obtained as to the relation een tendency to wear and the orientation of the of the cup. The jewels which I will project on the n with the aid of polarized light show clearly both vay in which the relationship between the basal and the tangent plane to the base of the cup may timated and the presence of other sources of weak- such as twinning planes. Photographs of most of jewels, together with a brief description of the s of interest demonstrated by each, have already red in the *Journal*.† I am interested in the r's suggestion that the tendency for rust to form service conditions between the pivot and the ire jewel may be partly, if not entirely, due to the cal constitution of the sapphire. His experiments fused silica support to some degree this theory. I d like to point out, however, that not only does orm of oxidation occur within a few seconds when gitation between the two surfaces is very severe—umping tests on electrical instruments—but it also place in the bearing, composed of a steel pivot ting in a hardened steel cup, which forms part of cheap clocks. In this case there can be no question affinity between the chemical constituents of the arts of the bearing, and the more generally accepted , that the oxidation is due to the infinitesimal size particles resulting from wear in the bearing, rs to be the more likely one.

. **F. Mercer:** The horological industry, to which I , is somewhat older than the meter industry. xperience of the use of jewels goes back nearly ears and deals with the effect of constant wear on apphires, and diamonds. The author's practice of ing his pivots on a carborundum wheel is contrary the traditions of the horological world. We use d-fashioned abrasives called "glossing stuff" and stuff," and afterwards we burnish the pivot well. ntine is worse than carborundum for this purpose. ld like to know whether the author refers to the l or to the artificial jewel when he mentions res. In our industry the natural stone is used exclusively. As regards the question of the rust particles that appear on pivots, when we examine an instrument that has been in service for two or three years, the first thing we do is to see whether the jewel hole has a green coating round it. If it has, we can be sure that the oil is functioning well but that it is getting slightly thick and needs replenishing. If, on the other hand, we see a red mark on the pivot, we know that there is insufficient lubrication. During the last few years such thorough investigations into the lubricating value of oil have been undertaken that I should have thought there would now be no difficulties in the way of using oil on meter pivots. If oil were so used and the pivots were cleaned and well polished, several years' running would be possible without rust forming on them. It is interesting to note the author's discovery that a diamond cut at an angle of 5° with the grain will rapidly wear away a steel pivot. I have also come across diamonds that have been used probably for 30 or 40 years in which a deep hole has been worn by the steel pivot, and the latter has retained its original shape.

Mr. E. G. Sandmeier: The tests conducted by the author are very interesting to me as a jewel maker, but when drawing conclusions from them it must be remembered that they were made on natural sapphires. In his complete paper he states that under ordinary microscopic inspection the jewels appeared to be perfect. However, even if a jewel appears to be perfect under ordinary microscopic examination, it cannot be perfect in reality if it exhibits twinning or internal strain such as that demonstrated by Mr. Ockenden. These two properties weaken the resistance to wear of the sapphire. I should like to ask the author whether the eight jewels which he examined had been inspected in polarized light, and, if so, whether they showed any defects such as twinning or internal strain. In his complete paper he mentions the fact that 9 out of 18 natural sapphires had been cut so that the tangent plane was nearly parallel to the basal plane of the crystal. This fact can be easily explained. One of the commonest varieties of natural corundum is built up of hexagonal, tabular bi-pyramids, sapphires from Montana being very often of this form. The jewel manufacturers have only to grind jewels of this type to the determined thickness; cutting the rough stone into plates is not necessary. They can then be turned into discs and polished. From the experience gained in this field I should not venture to draw any definite conclusions as to the best orientation of the cup, so long as I was not quite sure that the jewels tested were completely uniform in all their properties. With regard to the synthetic sapphire, I may state that the best direction for cutting the cup is parallel to the mechanical layers forming the synthetic stone. In perhaps 80 per cent of the synthetic jewels I have inspected, the tangent plane at the base of the cup is inclined at an angle of from 40° to 80° to the basal plane of the crystal. Incidentally, I may mention the fact that of the 19 natural sapphires I was able to examine* a year ago by the courtesy of Mr. W. Lawson, 3 had twinning, and it was impossible in these cases to establish the correct direction of the optic axis. Of the remaining 16, one was cut with an angle of 10° between the tangent plane and the

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Journal I.E.E., 1931, vol. 69, p. 658.

† *Loc. cit.*

* *Journal I.E.E.*, 1930, vol. 68, p. 1519.

basal plane. In another this angle was 19°, the remaining 14 jewels having angles from 46° to 89°. Of the 16 synthetic jewels, one was cut parallel to the basal plane, and the remaining 15 showed angles from 55° to 90°. I cannot understand why in the meter industry the bearing is not lubricated, because we who cut the jewels know very well that if there is no lubrication the jewel can be damaged by a softer material such as steel.

Mr. W. Lawson: The fact that the author found a difference in hardness of 25 per cent between two similar pivots throws considerable light on the subject of wear. If we could exercise the same degree of control in the manufacture of pivots and in the selection of jewels as the author has with his pivots, this problem would not exist. Fig. 4 suggests that in meters we might use pivots of considerably smaller radii than those adopted at present, and I should like to ask whether the author considers that any advantage would be gained by reducing pivot radii to, say, half their present values. This would mean that the speed of the rubbing surface would be greatly reduced, and if in addition we employed meters having very low rotor speeds we might be able to reduce the wear very considerably. The author has proved conclusively that the rotation of the pivot is one of the causes of rust, and in this connection he has disposed for ever of the oft-repeated suggestion of using stainless steel as the material for pivots, to obviate rust. As regards lubrication, he has confirmed what had previously been well established. In the case of the dry bearing, the frictional torque was actually 47 dyne-cm after the first half million revolutions, and with the lubricated jewel after it had begun to wear it was only 10 dyne-cm. It is therefore quite obvious that oil does lubricate, and particularly does it lubricate a worn bearing, although this is contrary to the statements of other investigators. The following are the results of some experiments which I recently carried out in this connection. A meter with a heavy rotor and a worn jewel was 8·7 per cent slow at 5 per cent load; after oiling it was 1 per cent slow. The error of another meter was reduced from 8·4 per cent to 4·8 per cent by means of oiling. By oiling a third meter, with a lighter rotor, I was able to reduce the error from 80·4 to 8·4 per cent. In one case the meter was slightly slower after the oil had been inserted, due, I believe, to the fact that the oil could not get down and come into contact with the two rubbing surfaces. I suggest that, in view of what the author tells us about the formation of rust in the presence of oil, his lubricated jewel probably started to wear as quickly as the dry jewel, but the presence of the oil delayed the effect. Fig. 10 shows wear which has the same characteristic as that of an ordinary meter jewel, i.e. there is an indication of side pressure. Would the author expect to get side pressure with his apparatus? His measurements of the friction at various intervals of time were not made under the long-run conditions; the position of the pivot when undergoing a friction test would be different from that which it occupied when the disc was held stationary by the magnet. I suggest that in any further investigation side pressure should be eliminated, so that when the test for friction is made the position of the pivot will be precisely the same as when it was wearing away the jewel. I do not agree with the author's statement that the results are of particular importance because it has been recommended that the jewel bearings should be run without lubrication, on the ground that this does not reduce the initial friction and that the oil eventually increases friction by collecting dirt or becoming resinous. The author's arrangement prevents dirt from collecting, because gravity tends to remove dirt from an inverted jewel, whereas in the more usual position of the cup both the dirt and the oil tend to sink down to the point of the pivot. With regard to the oil becoming resinous, it would be very bad oil that became resinous in 6 months, and, in fact, meters have to remain in service for more like 6 years. Where diamond jewels are employed, even this latter figure is greatly exceeded. I am interested to see that the author has definitely proved that rust increases the friction in a bearing. He found that a diamond used in conjunction with a steel pivot showed no signs of rust even after 2 million revolutions. While his explanation of the rust produced in an ordinary sapphire jewel is a reasonable one, in my opinion the rusting process is delayed in the case of the diamond jewel, because in the first instance the friction is of a lower order than it has been found to be with the sapphire —and it does not increase. It would be interesting to know whether the rusting increases with increase in the speed of the moving surfaces, and whether the author expects to get more rusting at the high speed (150 r.p.m.) which he employs. Many investigators have spent a great deal of time in trying to solve the problem of the wear of jewels, and this Section has already held three meetings at which the subject has been discussed. My statistics of the wear of jewels in modern meters show, however, that we are no nearer to a solution, as we are still getting jewels that show wear after only a few units have been registered on the meter.

Mr. E. Fawssett: I should like to ask the author whether he is quite sure that there was still some oil on the pivot after the 16 million revolutions. One or two of the previous speakers have assumed that the majority of users are running their meter bearings dry, but I do not think that this is correct. In my view, there now exist definite reasons why we should not do so. The qualities necessary in oil for lubricating light bearings are: (*a*) it should remain in its place without becoming gummy; (*b*) it should be absolutely stable and inert chemically. Our limited experience seems to show that animal and vegetable oils usually stay in the bearing, but they are usually chemically unstable, and become acid; whereas mineral oils are generally stable, but they creep out of the bearings. Most of the proprietary oils appear to be a mixture of animal and mineral, vegetable and mineral, or all three types of oils; based on the hope (usually not realized) that the advantages of each will outweigh the disadvantages of the others. We carried out an examination of various types of oils—animal, vegetable, and mineral—from the light end of the range down to the heavy turbine oils. First we exposed them to air out of contact with dust (under a bell-jar) for 12 months, on glass and on brass, to see whether they were chemically inert and whether they deteriorated or crept. We tried hydrocarbons, the best commercially available clock oils, castor oil, sperm oil, transformer oil, and medicinal araffin, as well as vaseline. Some striking effects were bserved. Vaseline set like hard wax. Transformer oil nd clock oil both crept so badly that they completely isappeared. All the others, except medicinal paraffin, ecame gummy and/or crept. Medicinal oil exhibited o change whatever, and only showed a slight tendency creep. We found that by coating the pivot and jewel ith a suitable varnish which is now available, this ndency to creep could be completely prevented. Our nsiderable practical experience of this treatment shows at it greatly increases the life of both pivot and jewel, increase in the friction being detectable even after millions evolutions. We recently made a control st of the relative merits of dry bearings and oiled earings by taking a series of meters of two different pes and running them under full-load conditions. All e pivots were made of specially-treated steel, tempered an exact temperature and shaped to an exact angle, d all the jewels were of special synthetic white sapphire d were produced by one manufacturer. The pivots d jewels were examined microscopically at intervals 3 million revolutions. At the end of the first run all e dry bearings were very rusty, and the oiled jewels ere free from rust. After the sixth run no appreciable mage had been done to any of the oiled bearings, yond the wearing of a very minute flat on the pivot, hich did not interfere at all with its working. These sults ought to dispose of a good deal of argument as whether or not it is advisable to oil meter bearings. e only objections to oiling have hitherto been the fficulties of (*a*) finding the right oil, and (*b*) keeping it its place. Both these objections have now been sposed of.

Mr. Wilfred Holmes: The author's results and the otographs exhibited by Mr. Ockenden show that some vance has been made in our knowledge of jewels and vots. The information given in the paper shows that itish meter manufacturers have been designing their oducts on the right lines. I am pleased that the thor has definitely disproved Fichter's dry-pivot eory. I note that the 10-million revolution tests scribed by the author were made under actual working ditions. This is very important, as I was reminded ne years ago when we as manufacturers were asked test some agate pivots on sapphire jewels. They were nd to be quite satisfactory under long revolution ts, but when they were put into service in meters ject to vibration they quickly cracked up. Following se experiments a large number of meters were tested ed with heavy discs having all kinds of pivots and els of all radii, some of the pivots being oiled, some . All the un-oiled pivots gave out before they had de 10 million revolutions, whereas every oiled pivot the correct shape was running for 100 million revolu- ns.* I notice that the author mounts his jewels d. It is usual to mount the jewel so that it is springy, there is considerable vibration in a meter.

Mr. A. H. Gray: The author showed on the screen jewels, one giving a bad and the other a good formance. I noticed that the background of the el giving a bad performance was grey, compared h the white background of the good jewel. I should like to know whether this grey background might not be due to the various inclusions found in natural sapphires. If so, would not these tend to confuse the issue? Can the author give any indication of the crystalline structure of an artificial sapphire? Mr. Ockenden stated that it is similar to that of the natural sapphire, although some X-ray analyses which I have had taken of artificial sapphires show that their crystalline structure is so complex that they cannot be definitely grouped in any particular lattice structure. I should be glad to know whether the author has made any investigations in this direction.

Mr. O. Howarth: There is no doubt that the principal financial losses with modern designs of a.c. meters are due to friction in the bottom bearing. The author's tests were made on pivots and jewels running not under the normal working conditions of an a.c. meter, but in a perfectly balanced condition. I should like to see figures giving the results of wear between the pivot and jewel in an ordinary a.c. meter when there is no revolution of the disc at all, but where the meter is merely energized, so that the usual vibration which occurs in such meters takes place between the pivot and jewel. Again, the pivot of an a.c. meter usually does not run right on the bottom of the jewel; there is side thrust, which may modify the author's results.

Mr. H. Horwood (*communicated*): The paper furnishes further proof, if any were needed, that the oiling of jewels and pivots considerably lengthens their useful life and improves their performance. This is further supported by the clock expert and the jewel manufacturer, who cannot understand why there is any question about it. At the discussion on Mr. Lawson's recent paper* on the same subject, in spite of submitted statistics showing the great superiority of oiled bearings to dry ones, there was a general opinion against the use of oil. I feel rather gratified at this change of front, as my firm has made meters with oiled bearings for some 30 years. I am interested in Mr. Fawssett's experiments on various lubricants, and his conclusion that meter bearings run best on liquid paraffin is very illuminating.

Dr. E. H. Rayner (*communicated*): The use of optical shadow methods with high magnification developed rapidly some years ago for the verification of the profile forms of such objects as screw gauges. Its use for fine instrument work as described in the paper shows what a powerful method it is, enabling profiles to be formed and measurements to be made in a simple manner which would be impracticable without it. Some years ago I developed a method of measuring pressures by forcing a hard steel point into a soft metal. The law between area of impression and pressure is the same as that found by the author for the crushing of steel points. The area is proportional to the pressure. Lead was used for low pressures and copper for higher pressures. An angle of 2 × 45° was chosen, as a sharper point tended to stick in the hole and there was risk of spoiling the impression on withdrawing it. The arrangement was used by the Electrical Research Association for the measurement of oil pressures in circuit breakers, being contained in a capsule which could be attached to any part of the mechanism. I am particularly interested in the author's work because it was due to my suggestion that the Department of Scientific and Industrial Research took the initial steps of discussing with representatives of a number of organizations the question of researches on the subject of pivots and jewels. It was decided that the great importance of this question made it desirable to initiate the researches of which an outline is given by the author. The subject has proved to be one requiring the resources of both physical and mechanical laboratories. The crystallographic factors mentioned by the author and his tentative suggestion as to the possible chemico-physical reaction at the interface between steel and alumina when there is relative motion with intense pressure, are very interesting, and it is hoped that they will be followed up. He mentions that the very close similarity between the forms of the oxides of iron and those of aluminium suggested to him a possible cause of rusting. Is there a convenient oxide of aluminium, other than sapphire, which would not be so closely similar to iron oxide? Another line of research which suggests itself is to try to use as jewels materials which do not contain oxygen. There are a number of binary and ternary carbides which might possibly be used. Is there any indication of "stiction" at very small relative velocities, say, between 1 and 0·001 r.p.m.? Information on this point would be of interest and might lead to new knowledge as to the mechanical and physical condition of the interface between the two materials. From a technical and commercial point of view the subject is of some importance. The annual output of electric power in this country is 9 000 million kWh, which is practically all generated as alternating current. In the course of its career it is no doubt all measured twice over by induction meters, and frequently three or four times. If the cost is represented by 1d. per unit the total daily cost is £100 000, so that improvements in meter performance would represent a sum of £100 per day if they caused a change of 1 part in 1 000 in the amount registered. The use of pivots and jewels in integrating meters was only one of the factors which led to the research being initiated. Pivots and jewels are used in many types of electrical and other instruments, but the integrating meter with its vertical axis, combined with continuous rotation and large loads relatively to other uses of pivots, constitutes a design more easily investigated than others.

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* *Journal I.E.E.*, 1929, vol. 67, p. 883.

* *Journal I.E.E.*, 1929, vol. 67, p. 1147.

Mr. H. C. Turner (*communicated*): I should like to ask the author whether, having set up an elaborate investigation apparatus, he has kept it in commission and will continue the work when a favourable opportunity occurs. It would be interesting to know whether any progress has been made in the use of tungsten, tungsten steel, or manganese steel, for the manufacture of pivots. With reference to the author's suggestion that the rust on the steel pivot comes from the decomposition of the sapphire (Al_2O_3), one would expect that if the oxygen had been used in the formation of rust, metallic aluminium would have been formed. Perhaps the author will state whether this actually occurred in the course of his experiments.

Mr. C. H. Wright (*communicated*): It may be of interest to refer to the results of some tests on pivot friction which I carried out in connection with the late Mr. M. B. Field's paper on "The Navigational Compass Considered as an Instrument of Precision."* The impression left on the mind when one makes a large number of tests, even on the same pair (pivot and jewel), is the somewhat variable nature of the pivot friction and the difficulty of setting down close values which may be taken as generally applicable. The results referred to were restricted to one load, namely, 15 g (the weight of the 10-inch Kelvin dry compass card), the pivots being osmi-iridium and the jewels natural sapphire. Tests on agate-sapphire pairs generally showed greater friction under the same load. The radius of curvature of the agate pivot points was much greater than that of the osmi-iridium points, and that of the corresponding sapphire cup greater accordingly. The values for the frictional torque, measured as nearly as possible as static friction effect, are somewhat different from those obtained by kinetic tests. As the author is chiefly concerned with electricity meters he deals mainly with the friction as exhibited in continuous motion between the elements of the pair, but static friction is of importance in some other connections. The author deserves the thanks of instrument makers for the interesting methods he describes for giving to pivots the desired shape, for his investigation of the best radii of curvature, for the method of test which produced the results given in Table 3, and for his tests on wear. This work is of special interest to electricity meter makers; those engineers who make and use electrical indicating instruments in which the pivot axis is horizontal, have to deal with rather different problems. Since in such cases it is not usually practicable to arrange for each pivot point to bear on the apex of the jewel cup, there is a tendency for the pivot to roll up the jewel. Thus other considerations than those of the actual pivot point may come in which cannot be treated in the straightforward way described by the author. Rust formation on steel pivots in electrical instruments has under some conditions been troublesome. Once formed, it seems to act as an abrasive, so that rapid wear may result. Many years ago this trouble was apparent in connection with instruments in service in certain parts of India, and osmi-iridium was successfully employed instead of steel for the pivots.

Mr. V. Stott (*in reply*): Mr. Ockenden has rightly drawn attention to the importance of taking into account the composition and structure of steel used for pivots. So far as the results given in Table 4 of the paper are concerned, however, the object of the experiments was to determine whether differences in wear could be observed with sapphire jewels of different orientation. For this purpose the main requirement of the pivots was that they should be comparable one with another, and I am satisfied that the pivots used can be regarded as comparable. I agree about the utility of examination in polarized light, but it should be remembered that the determination of the angle between the optic axis and the normal to the tangent plane at the base of the jewel cup does not completely give the orientation of the jewel. The complete crystallographic indices of the tangent plane as obtained by X-ray methods are necessary fully to define the orientation. When a steel pivot is working against a hardened steel surface there is much greater possibility of molecular cohesion between the material of the pivot and that of the bearing surface than when two different materials, e.g. steel and sapphire, are in contact. The view that, as a result of molecular cohesion and relative motion, small particles of iron become detached and immediately oxidize to form rust, appears to fit in quite well with the formation of rust on a steel pivot in contact with a hardened steel surface. This, however, is not at all inconsistent with the suggestion that when a steel pivot rotates in contact with a sapphire jewel the rust formed derives its oxygen from the sapphire. In this instance molecular cohesion between the iron in the steel and the oxygen in the sapphire is a conceivable mechanism for the formation of rust without the intervention of oxygen from the atmosphere.

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* *Journal I.E.E.*, 1919, vol. 57, p. 375.

In reply to Mr. Sandmeier the natural sapphire jewels were examined in polarized light and showed no evidence of twinning or internal strain. Mr. Sandmeier's statement that the best direction for cutting the cup is parallel to the mechanical layers forming the synthetic stone, is of interest and importance. It leads directly to the conclusion that with synthetic sapphire the orientation of the jewel relative both to the crystallographic axes and to the " mechanical layers " needs to be taken into account, particularly in view of the next sentence in Mr. Sandmeier's communication, from which it would appear possible that there is not a constant relation between the mechanical layers and the crystalline structure.

Mr. Lawson asks whether any advantage would be gained by reducing pivot radii to half their present values. I would not venture an opinion on this without first carrying out practical work to obtain direct experimental evidence on the point. I do not think that the possibility of variation in the point of contact of the pivot and jewel on the apparatus during the wear test and when the frictional torques were measured was such as to invalidate any conclusion drawn from the friction measurements. I have no experimental evidence to show whether the amount of rust produced for a given number of revolutions varies with the speed of rotation. Grunberg* argues, however, that the total wear is dependent on the total number of revolutions rather than on the speed of rotation, and he carried out wear tests with a speed of 800 r.p.m. which, he says, gave results quite comparable with those obtained in meters.

In reply to Mr. Fawssett, at the end of 16 million revolutions there were oil-film interference colours visible under the microscope on the flat rim of the jewel and for some little way inside the cup. There were also traces of oil-film colours on the flanks of the pivot. Some oil therefore remained in the bearing at this stage, but it was inadequate in amount to prevent an increase in friction with continued rotation of the pivot, as indicated by the increase in friction at this stage of the test. It is interesting to note that Mr. Fawssett has found that the use of medicinal paraffin as a lubricant, combined with treatment of the pivot and jewel surfaces to prevent creep of the oil, has given very satisfactory results.

The grey background referred to by Mr. Gray is due to out-of-focus images of the ground surface at the back of the jewel and does not indicate the presence of inclusions. The crystalline structure of synthetic sapphire jewels has been found to be the same as that of natural jewels. The structure of a boule of synthetic sapphire has also been determined and the orientation was found to be constant throughout the whole boule.

Mr. Howarth's suggestion that experiments should be carried out on the effects of vibration alone without rotation, and also on the effects of side thrust, is of interest. They serve to illustrate the number of variables which have to be taken into account in studying the wear of pivots and jewels. Such variables have not been lost sight of, but, in the initial stages of the work, it seemed advisable to keep the conditions as simple as practicable, in order to have as full a control as possible of the variable factors.

In reply to Dr. Rayner, there is no oxide of alumina other than Al_2O_3 which is convenient for use as a jewel. As regards the magnitude of the friction at very low relative speeds, an inspection of velocity/time curves such as those in Fig. 32 of my more complete paper* show that there is no change in slope of the velocity/time curves as the disc comes to rest. Any appreciable change in the frictional torque at low speeds, as compared with higher speeds, would be indicated by a change in the slope of the velocity/time curves at the low speeds prevailing before the disc finally comes to rest.

In reply to Mr. Turner, the British Electrical and Allied Industries Research Association have made arrangements for further work to be carried out on their behalf with the apparatus at the National Physical Laboratory. I have no information as to the progress made in the use of alloy steels for pivots. The only evidence bearing on the possible production of metallic aluminium under the circumstances mentioned by Mr. Turner is the presence of very faint aluminium lines in the spectrum obtained by sparking the debris formed by a stellite pivot and sapphire jewel (see page 363).

FURTHER INVESTIGATIONS BY THE AUTHOR.

When the paper was read before the Meter and Instrument Section, mention was made of further work which had been in progress since the publication of the original paper. A series of wear tests have provided results of some interest in themselves and have also led to a new idea regarding the formation of rust on a steel pivot rotating in contact with a sapphire jewel. It seems appropriate to give a brief account of this work for publication with the report of the discussion on the original paper.

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* G. GRUNBERG: *Revue Générale de l'Électricité*, 1930, vol. 28, p. 273.

* " National Physical Laboratory Collected Researches," vol. 24, Paper No. 1.

Wear Tests with " Stainless Steel " Pivots and Sapphire Jewels.

The pivots were made from steel of the following percentage composition: carbon 0·39, silicon 0·51, sulphur 0·028, phosphorus 0·024, nickel 0·17, chromium 12·45, and a trace of manganese. Two pivots were used, each terminating in a 60° cone finished at the apex into a portion of a sphere of 1/32 in. diameter. One of the pivots was made from the steel as supplied and the other from the same material after hardening. The limiting load per unit area obtained by loading a 120° cone of the first material was 242 kg per mm^2, and that for the hardened material 667 kg per mm^2.

The softer pivot (No. 333) was used in a wear test on a blue synthetic-sapphire meter jewel (No. 56) having a radius of curvature of 1·24 mm; the orientation of the jewel was such that its axis was normal to a plane having the indices 0·64 : 1 : 1·97 (rhombohedral axes $a = 55° 17'$). The harder pivot (No. 334) was used with a similar blue synthetic-sapphire meter jewel (No. 45) of radius of curvature 1·26 mm and orientation 0·62 : 1 : 1·43. The tangent to the base of the cup of jewel No. 45 made angles of 36° 6′ with (111) and 54° 24′ with ($\bar{1}01$), and the corresponding angles for jewel No. 56 were 45° 54′ and 45° 15′. Thus there was not a very large difference in the orientation of the jewels.

In the wear tests the pivots rotated at a speed of approximately 100 r.p.m., the jewels remained stationary, the load on the pivots was 25 g, and no lubrication was employed. The frictional torque between the pivots and jewels was measured at intervals throughout the wear test, which was interrupted when each pivot had completed 1 million revolutions. The pivots and jewels were then cleaned and the test continued until each pivot had completed a further 2 million revolutions. Friction measurements were taken at intervals throughout the test after removal of the magnets employed to keep the discs stationary during the wear test, i.e. under a load of 20 g. A selection from these measurements which serve to show the increase in the friction are given in Table 5.

It is interesting to note that both initially and at the end of the test there was not much difference between the frictional torques obtained with the soft (No. 333) and the hard (No. 334) pivots. During the earlier stages of the test the friction increased more rapidly with the hard than with the soft pivot. During the wear tests a flat was worn at the end of each pivot, and actually a larger flat was worn on the hard pivot than on the soft one, as shown in Table 6.

An important feature of the wear tests was that heavy deposits of rust—precisely similar to those obtained with ordinary steel pivots—were formed with the stainless-steel pivots. The somewhat erratic variation of the friction measurements in the later stages of the test was doubtless due to the presence of this rust. There was very little difference in the condition of the two jewel surfaces after the tests, neither being very badly damaged.

Wear Tests with Steel Pivots and Fused Silica Jewels.

Two pivots and two jewels were used for the tests. The pivots were made by mounting Hoffmann hardened steel balls of 1/32 in. diameter on brass wires. One pivot (No. 360) had a diamond pyramid hardness number 890 kg per mm^2, and the other (No. 362), 1 120 kg per mm^2. The fused silica jewels each had a radius of curvature of approximately 4·4 mm. The conditions of load and speed during the wear tests were the same as for the stainless-steel pivots, and no lubrication was employed. The results obtained in the friction measurements made with a load of 20 g are given in Table 7.

TABLE 5.

Results of Friction Measurements During Wear Tests with Stainless-Steel Pivots and Synthetic-Sapphire Jewels.

Number of revolutions completed by pivot	Measured frictional torque	
	Pivot No. 333 (hardness 242 kg per mm^2), Jewel No. 56	Pivot No. 334 (hardness 667 kg per mm^2), Jewel No. 45
	dyne-cm	dyne-cm
0	0·7	0·9
30 000	15	29
130 000	21	49
298 000	31	64
640 000	37	56
1 010 000	35	72
1 010 000 (after cleaning) ..	16	67
1 524 489	38	55
1 988 316	60	80
2 500 316	30	55
3 238 316	77	84
3 238 316 (after cleaning) ..	39	49

The increase in friction was very much greater than with steel pivots and sapphire jewels, but here again the harder pivot showed a more rapid increase in friction.

TABLE 6.

Amount of Wear of Stainless-Steel Pivots.

Number of revolutions completed by pivot	Pivot No. 333 (soft)		Pivot No. 334 (hard)	
	Diameter of flat at end of pivot	Volume of material removed from pivot	Diameter of flat at end of pivot	Volume of material removed from pivot
	mm	mm^3	mm	mm^3
1 010 000	0·135	0·000025	0·22	0·00017
3 238 316	0·225	0·000201	0·34	0·00116

There was a very marked difference in the effects of wear on the pivots and jewels as compared with steel pivots and sapphire jewels. The effects of wear on a steel pivot and sapphire jewel are to produce a flat on the end of the pivot, but the profile of a section through the jewel remains practically unchanged. With the steel pivots and fused silica jewels the effects of wear

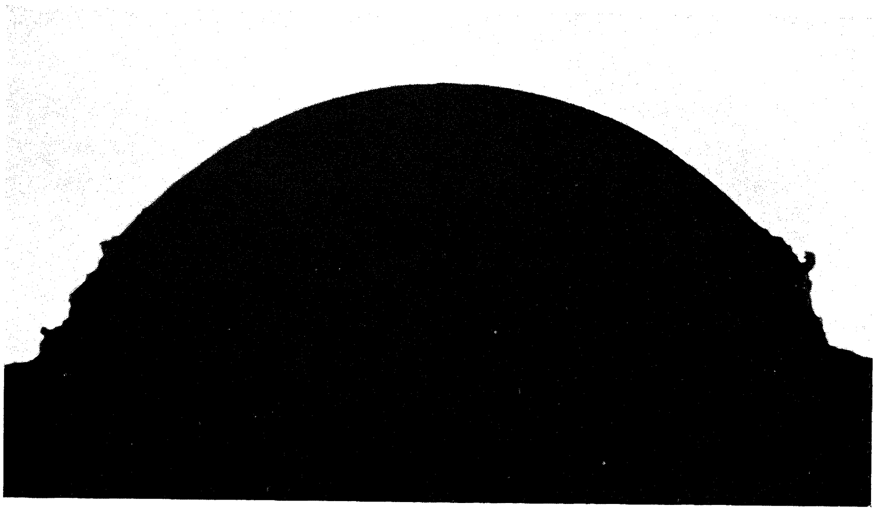

FIG. B.—Profile of steel pivot (No. 362) after a million revolutions in contact with fused silica jewel (No. 79). Magnification = 160.

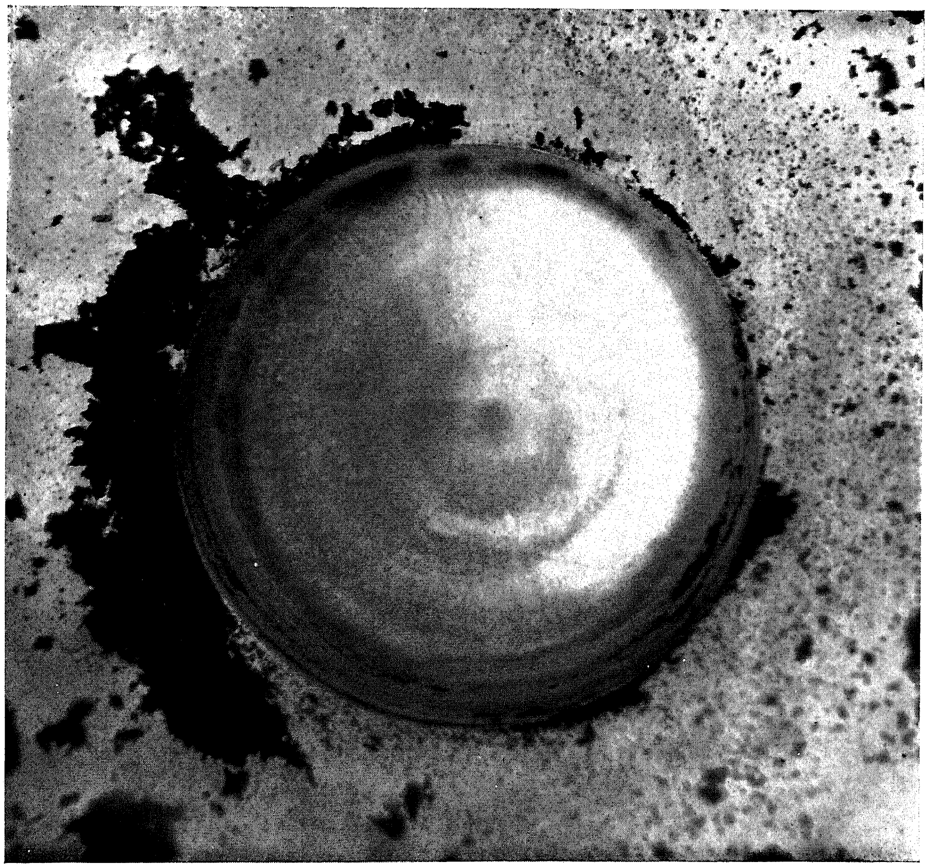

FIG. C.—Surface of fused silica jewel (No. 79) after a million revolutions in contact with steel pivot (No. 362).

were just the reverse. The profile of the pivots remained unchanged, but the fused silica jewels suffered severe wear. The pivot bedded itself in the jewel, wearing a depression having the same radius of curvature as the pivot. The diameter of the top of the depression at the end of the wear test was 0·55 mm on jewel No. 78, and 0·56 mm on jewel No. 79. The profile of pivot No. 362 at the end of the test (i.e. after 1 010 000 revolutions) is shown in Fig. B (see Plate), and the surface of jewel No. 79 at the end of the test is shown in Fig. C (see Plate). The clearly-defined circle in Fig. C is the rim of the depression worn by the pivot.

The debris formed during the test was an opaque white powder, doubtless silica from the depression worn in the jewel, and it is significant that no rust was formed. The surfaces of the pivots at the end of the test had a matt appearance but were quite free from rust.

TABLE 7.

Results of Friction Measurements During Wear Tests with Steel Pivots and Fused Silica Jewels.

Number of revolutions completed by pivot	Measured frictional torque	
	Pivot No. 360 (hardness 890 kg per mm^2), Jewel No. 78	Pivot No. 362 (hardness 1 120 kg per mm^2), Jewel No. 79
	dyne-cm	dyne-cm
0	1·1	1·3
30 000	37	97
130 000	46	93
170 000	139	123
218 000	76	171
298 000	60	127
420 000	70	90
520 000	181	185
640 000	237	208
800 500	158	267
1 010 000	171	297
1 010 000 (after cleaning)	159	146

The results of these tests indicate that steel pivots and fused silica jewels do not form a satisfactory combination.

Wear Tests with Sapphire Pivots and Sapphire Jewels.

Two sapphire pivots (Nos. 92 and 93), each having a radius of curvature at the end of 0·32 mm, were used for the tests. The orientation of the pivots relative to the crystalline structure has not yet been determined. Two white synthetic-sapphire meter jewels were used with the pivots. One jewel (No. 62) had a radius of curvature of 1·24 mm and the indices of a plane tangent to the base of the cup were 0·56 : 1 : 6·30, giving an angle of 65° 17′ on (111) and of 33° 48′ on $(\bar{1}01)$. The other jewel (No. 63) had a radius of curvature of 1·18 mm and indices 0·98 : 1 : 1·20, giving an angle of 10° 35′ on (111) and of 79° 31′ on $(\bar{1}01)$.

The wear tests were carried out under the same conditions of load and speed as for the tests recorded in the preceding paragraphs, and again no lubrication was employed. The results obtained in the friction measurements with a load of 20 g are given in Table 8.

From Table 8 it is clear that the combination of a sapphire pivot and sapphire jewel shows a very small increase in friction relative to that which occurs with steel pivots running on sapphire jewels without lubrication. Grunberg's wear experiments also showed that sapphire pivots give much longer service than steel pivots.*

In view of previous results† it is interesting to note that the increase in friction was distinctly more marked with jewel No. 63, of which the axis was almost normal to the plane (111), than with jewel No. 62.

On examination of pivot No. 92 under the microscope at the end of the test, a well-defined ring 0·1 mm in diameter—made up of small particles less than 1/120 mm in diameter—was noticed round the end of the pivot. There was a small amount of similar debris on jewel No. 63. There was no visible change in the profile of the pivot or any signs of damage to the jewel surface. The appearance of pivot No. 93 and jewel No. 62 was similar, but there was distinctly less debris, particularly on the jewel.

TABLE 8.

Results of Friction Measurements During Wear Tests with Sapphire Pivots and Sapphire Jewels.

Number of revolutions completed per pivot	Measured frictional torque	
	Pivot No. 92, Jewel No. 63 (approximate indices 1 : 1 : 1)	Pivot No. 93, Jewel No. 62 (approximate indices 1 : 2 : 11)
	dyne-cm	dyne-cm
0	0·9	1·1
286 173	1·1	1·3
500 001	2·4	1·2
750 000	1·8	1·5
1 012 000	2·7	1·8
1 262 000	3·4	1·4
1 412 000	2·4	1·4
1 715 000	3·3	2·0
2 000 000	3·0	1·9
2 000 000 (after cleaning)	4·2	1·3

The increase in the friction between pivot No. 92 and jewel No. 63 after cleaning at the end of the test is unusual. The surface of the jewel or pivot may have been damaged when the debris was being removed.

As jewel No. 63 did not appear to have suffered any damage, it was used again in a wear test, which is still in progress at the time of writing. In this wear test it was used with a new sapphire pivot of radius of curvature 0·31 mm. The test began on the 26th October, 1931, and the conditions of the test were the same as those just described, with the exception that a drop of clock oil was placed on the pivot and the jewel cap was filled with clock oil before starting the wear test. The results of the friction measurements obtained to date (21st December, 1931) are given in Table 9.

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* G. GRUNBERG: "Researches on the Performance of Pivot Systems of Electricity Meters," *Revue Générale de l'Électricité*, 1931, vol. 29, p. 869.

† *Collected Researches of the National Physical Laboratory*, vol. 24, Paper I, p. 47.

The close agreement between the first two figures in the second column of Table 9 confirms once more that the presence of oil has no significant influence on the magnitude of the initial frictional torque. Comparing the last column of Table 8 with the second column of Table 9, it is seen that with pivot No. 93 and jewel No. 63 run dry the friction changed from 1·1 to 1·9 dyne-cm in the first 2 million revolutions, an increase of 0·8 dyne-cm, whilst with pivot No. 94 and the same jewel (No. 63) run with lubrication the change in the friction during the first 2 million revolutions was from 0·9 to 1·3 dyne-cm, an increase of 0·4 dyne-cm. Hence, although the increase in friction was somewhat less with oil present, the difference between the increase in friction with and without oil is of a very different order from the results obtained with steel-sapphire bearings with and without oil, for which combination the increase in friction without oil was very much more marked than with oil.*

TABLE 9.

Results of Friction Measurements During Wear Tests with Sapphire Pivot No. 94 and Sapphire Jewel No 62 (approximate indices 1 : 2 : 11). Pivot and Jewel Lubricated with Clock Oil.

Number of revolutions completed by pivot	Measured frictional torque
	dyne-cm
0 (without oil)	$0\cdot8_5$
0 (with oil)	$0\cdot9_5$
250 000	0·9
382 000	0·9
605 258	1·0
887 258	0·9
1 137 258	1·1
1 382 000	1·1
1 787 000	1·3
2 000 000	1·3
2 370 000	1·6
2 710 000	2·4
3 000 000	2·8
3 475 000	3·2
4 007 000	3·6

From 2 million revolutions to 4 million revolutions the friction between pivot No. 94 and jewel No. 63 increased (see Table 9) at a practically steady rate of approximately 1 dyne-cm per million revolutions.

Wear Tests with Steel Pivots and Diamond Jewels.

Hoffmann hardened steel balls 1/32 in. diameter mounted on brass wires were used as pivots. Five balls were selected, four of which (Nos. 443, 444, 446, and 447) had a diamond pyramid hardness number of 1 050 kg per mm², and the fifth (No. 450) had a hardness number of 1 070 kg per mm². The diamond jewels used with the pivots each had a radius of curvature of approximately 2·6 mm. The determination of the orientation of the diamonds has been deferred, as the metal mounting gave rise to difficulties and it was desired not to disturb it until after the wear tests.

The pivots and jewels were used without lubrication, and the conditions of the wear-test and friction measurements were the same as those of the wear tests described in the preceding paragraphs.

The tests are still in progress, but as the results so far obtained have an important bearing on the views to be put forward subsequently in these notes, they are summarized in Table 10.

TABLE 10.

Results of Friction Measurements During Wear Tests with Steel Pivots and Diamond Jewels.

Number of revolutions completed by pivots No. 443, 444, 446, and 447	Measured frictional torque					Number of revolutions completed by pivot No 450
	Pivot No. 443, Jewel No. 86	Pivot No. 444, Jewel No. 87	Pivot No. 446, Jewel No. 88	Pivot No. 447, Jewel No. 89	Pivot No. 450, Jewel No. 90	
	dyne-cm	dyne-cm	dyne-cm	dyne-cm	dyne-cm	
0	0·6	0·7	0·6	0·6	0·6	0
605 258	1·7	0·9	0·8	1·1	0·7	223 258
1 137 258	1·3	0·7	0·6	0·7	0·6	755 258
2 000 000	1·6	1·0	1·0	0·8	0·7	1 618 000
3 000 000	1·1	0·9	0·7	0·7	0·7	2 618 000
3 475 000	1·2	0·8	0·6	0·7	0·7	3 093 000
4 007 000	1·1	0·9	0·6	0·8	0·7	3 625 000
4 340 000	1·2	0·9	0·6	0·9	0·8	3 958 000
5 000 000	1·0	0·9	0·6	0·8	0·7	4 618 000
5 525 000	0·9	0·9	0·6	0·8	0·7	5 143 000
6 185 000	1·1	0·9	0·6	0·9	0·8	5 803 000
6 815 000	0·9	0·9	0·6	0·8	0·9	6 433 000
7 580 000	0·8	1·0	0·6	0·8	0·7	7 198 000
8 850 000	1·1	0·9	0·9	0·8	0·8	8 468 000

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* See *Journal I.E.E.*, 1931, vol. 69, p. 755; also *Collected Researches of the National Physical Laboratory*, vol. 24, Paper I, p. 39.

From Table 10 it will be seen that even in the absence of lubrication the friction between the steel pivots and diamond jewels remained extremely low for a number of revolutions which under similar conditions would have caused very large increases in the friction between a steel pivot and sapphire jewel.

Pivot No. 444 and jewel No. 87 were examined under the microscope after 2 million revolutions. Neither showed any trace of rust. There was a circular mark on the jewel of 0·3 mm diameter composed of small dark particles, the largest of which were 0·017 mm in diameter. After 4 million revolutions there was again no trace of rust on either pivot or jewel. There was rather more dark metallic-looking material on the surface of the diamond, mainly disposed on a ring 0·33 mm in diameter. There were a number of elongated particles approximately 0·017 mm by 0·002 mm, having a slight tendency towards radial arrangement. After nearly 9 million revolutions the pivot and jewel were still free from rust, and there was on the diamond an irregular area, again about 0·33 mm in diameter, sparsely covered with a dark deposit.

The results so far obtained are markedly different from those of previous tests with sapphire jewels and similar steel pivots made by mounting 1/32-in. diameter steel balls on brass wires. In these earlier tests there was a large increase in friction and copious formation of rust.

Wear Test with Stellite Pivot and Sapphire Jewel.

The stellite pivot was made from stellite cast into rods 2 mm in diameter by the Metallurgy Department. The results of a chemical analysis of the stellite were:—Tungsten 11·78 per cent, iron 4·54 per cent, chromium 29.36 per cent, cobalt 52·89 per cent. The pivot was finished to a 60° cone terminating in a portion of a sphere 0·44 mm diameter. The spherical surface was not very good, as it had some small flat facets on it. The hardness of the pivot was 870 kg per mm^2 (load per unit area with 120° cone). The jewel used was a white synthetic-sapphire meter jewel of radius of curvature 1·28 mm and orientation — 0·37 : 1 : 1·05. The friction measurements obtained during the wear test are given in Table 11, the conditions being the same as in the experiments described in preceding paragraphs. No lubrication was employed.

The increase in friction was very rapid, being as great (see Table 7) as that with steel pivots and fused silica jewels. On examination under the microscope both pivot and jewel were found to be heavily coated with nodules almost white in colour, but having a very pale purplish-brown tinge. Except for the difference in colour the appearance of the deposit was very similar to that of the rust formed on a steel pivot rotating in contact with a sapphire jewel.

The total weight of deposit formed was only a few hundredths of a milligram, but was very conspicuous when the pivot and jewel were viewed under the microscope. Thus a very small weight of debris produced very considerable increase in friction.

It appeared to be a matter of some interest to obtain such information as to the composition of the debris as was possible with the small quantity of material available.* In preliminary chemical tests the debris was transferred to the point of the closed end of a capillary tube and dissolved in dilute hydrochloric acid. A blue-green solution was obtained, the colour of which was practically lost on dilution; a black precipitate was formed when the solution was saturated with bromine and made alkaline with caustic soda. These reactions are characteristic of cobalt.

A further quantity of debris was prepared by running the pivot and jewel again as in the wear test. A spectroscopic examination of the debris on the jewel was made by sparking a pair of gold electrodes to one of which the powder had been transferred as completely as possible by means of a small glass rod. The spectrum showed very clearly the presence of cobalt and of chromium; a very faint line due to aluminium was also recognized. The intensity of the cobalt lines was approximately equal to that found when a drop of a cobalt-chloride solution containing 0·01 mg of cobalt was evaporated on the electrode and sparked similarly. Since tungsten had not been identified in the spectrum of the powder, there was also added to the drop of solution 0·002 mg of tungsten (as sodium tungstate) and it was established that this quantity of tungsten would not have been detected by the procedure used.

TABLE 11.

Results of Friction Measurement During Wear Test with Stellite Pivot No. 413 and Sapphire Jewel No. 60.

Number of revolutions completed by pivot	Measured frictional torque
	dyne-cm
0	2·9
103 168	78
332 865	151

Material rubbed off from the top of the pivot on to the gold electrode gave a similar spectrum.

Suggested Explanation of the Formation of Rust on Steel Pivots Rotating in Contact with Sapphire Jewels.

In the original papers† the author suggested that Tomlinson's explanation of rust formation on steel surfaces in contact with each other might be extended to explain the formation of rust when a steel pivot rotates in contact with a sapphire jewel. On this view minute particles of iron become detached from the pivot owing to molecular cohesion between the pivot and jewel, and immediately become oxidized by the oxygen of the atmosphere to form the deposit of rust.

The further wear tests recorded above have, however, suggested the possibility of a different explanation of the formation of rust. In the wear tests with steel pivots and diamond jewels the mechanical conditions were the same as in the tests with steel pivots and sapphire jewels, and one might have expected a similar detachment of small particles of iron and their oxidation by the atmosphere. This, however, did not occur: no rust at all was produced by the diamond jewels. Again, no rust was formed in the wear tests with steel pivots and fused silica jewels.

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* The analysis of the stellite and the examination of the debris was carried out in the Metallurgy Department of the Laboratory.

† *Journal I.E.E.*, 1931, vol. 69, p. 751; also *Collected Researches of the National Physical Laboratory*, vol. 24, Paper 193.

In view of these facts it appears to be possible that the oxygen of the rust formed when a steel pivot rotates in contact with a sapphire jewel comes not from the atmosphere but from the sapphire. Sapphire is aluminium oxide (Al_2O_3) and has a crystalline structure very similar to that of ferric oxide (Fe_2O_3). Both oxides belong to the ditrigonal scalenbohedral class of symmetry, the rhombohedral angle of sapphire being 93° 59½′ (Groth) and that of ferric oxide 93° 45′ (Groth). It may be that this similarity in crystalline structure is a factor in the formation of rust by transference of oxygen from the sapphire to the steel, for although oxygen is present in fused silica no rust was formed in the wear tests with steel pivots and fused silica jewels. Again, chromium oxide (Cr_2O_3) crystallizes in the ditrigonal scalenbohedral class like Al_2O_3 and Fe_2O_3, and has a rhombohedral angle 94° 17½′ (Groth) very nearly equal to the rhombohedral angle of sapphire.

There is perhaps some connection between this fact and the rapid development of debris when stellite pivots, containing about 30 per cent of chromium, rotate in contact with sapphire jewels. It would also suggest that there are serious doubts whether chromium-plated steel pivots—which have sometimes been proposed—would prove successful.

There is evidence to suggest the possibility that the formation of a deposit, the accumulation of which gives rise to increase in friction and is very detrimental to the efficient functioning of a pivot and jewel bearing, may be influenced not only by the mechanical production of debris but also by chemical action between the pivot and jewel. When sapphire pivots were run with sapphire jewels, a combination in which chemical reaction would not be anticipated, the debris formed was very small in amount compared with the rust which develops on a steel pivot in contact with a sapphire jewel, and the friction remained much smaller. Similarly, the amount of debris obtained with steel pivots and diamond jewels was very small, and the frictional torque remained low.

In considering the choice of materials for pivots and jewels, one should bear in mind the possibility of chemical action between the materials under the conditions of rotation under great pressure existing in such a bearing. If the view now put forward has any validity, steel and sapphire would appear to be an unfortunate combination of materials. It is conceivable that tolerable efficiency has only been possible with steel pivots and sapphire jewels by employing lubrication. The oil presumably prevents for some time the intimate contact between the steel and sapphire necessary for an exchange of oxygen between them. If the oil is not renewed, rust is ultimately formed when lubricated steel pivots are used with sapphire jewels. Even at this stage the oil perhaps tends to lessen the increase in friction resulting from rust formation, as the rust becomes disseminated throughout the oil instead of accumulating at the area of contact.

It is interesting to note that Major Gould finds that the bearings of steel and lignum vitæ employed in old chronometers made by Harrison will function satisfactorily without lubrication. This again is possibly due to lack of chemical affinity between the wood and the steel.

It is not claimed that sufficient work has been done fully to establish the views now put forward, but it is suggested that they open up a new line of attack on problems of wear in pivot and jewel bearings which should repay further investigation.

POLYPHASE COMPENSATED COMMUTATOR INDUCTION MOTORS.*

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(*Paper first received* 19*th December*, 1930, *and in final form* 29*th June*, 1931.)

SUMMARY.

After a brief reference to phase advancers, the Heyland motor and its modifications and the Osnos motor (to which the paper is chiefly devoted) are described. The theory of the Osnos motor, which is also known by its trade names of "No-Lag" and "Kosfi-Leading," is then developed, and the equivalent circuits, test results, circle diagrams, and verification of the theory of the machine are given. A general method of obtaining the copper loss, output, torque, etc., from the circle diagram of any motor is developed; an example is worked out and the results so obtained are compared with test figures. A description follows of the Fynn-Weischel and Torda motors (known also by their respective trade names of "Tru-Watt" and "All-Watt"), and the principle of action and characteristic curves of these machines are given.

LIST OF SYMBOLS.

The following symbols relate to the Osnos motor. All primary quantities are per phase, and all secondary and commutator quantities are also per phase (star value) and are reduced to primary, unless otherwise stated.

b = susceptance of the main circuit.
b_0 = exciting susceptance of the motor when running as an ordinary induction motor.
E = e.m.f. consumed by the voltage induced in the primary by the main flux.
E_1 = primary impressed e.m.f.
E_2 = secondary open-circuit voltage (unreduced).
E_a = commutator e.m.f.
f = frequency of supply.
g = conductance of the main circuit.
g_0 = exciting conductance of the motor when running as an ordinary induction motor.
I = current in the main circuit.
I_0 = magnetizing current of the motor when running as an ordinary induction motor.
I_0' = current in the shunt circuit.
I_1 = total primary current.
I_2 = primary current required to overcome secondary ampere-turns.
I_2' = secondary current (unreduced).
$j = \sqrt{(-1)}$.
k = ratio of commutator e.m.f. to secondary open-circuit e.m.f.
k_1 = ratio of primary impressed e.m.f. to secondary open-circuit e.m.f.
$m = k \cos \beta$.

LIST OF SYMBOLS—*continued*.

$n = k \sin \beta$.
r_1 = primary resistance.
r_2 = secondary resistance.
r_2' = secondary resistance (unreduced).
r_a = resistance of the commutator winding.
R = total resistance of the main circuit
$R_2 = r_2 + r_a$.
s = fractional slip of the motor.
x_1 = primary leakage reactance.
x_2 = secondary leakage reactance.
x_2' = secondary leakage reactance (unreduced).
$X = x_1 + x_2$.
$\left.\begin{matrix}(x_c, y_c)\\(X_c, Y_c)\end{matrix}\right\}$ = co-ordinates of centres of circles.
(x_n, y_n) = co-ordinates of the extremity of the vector representing the current in the shunt circuit.
$Z_1 = r_1 + jx_1$.
β = lead of the commutator e.m.f. over the the secondary e.m.f.
$\gamma = E_1/(2X)$.
$\delta = kE_1/(2R_2)$.
ψ = phase difference between I and E_1.
ϕ = phase difference between I_1 and E_1.

INTRODUCTION.

In 1888 Nikola Tesla invented, with others hot on the trail, the epoch-making induction motor, which has played such an important part in the development of industries all over the world. The engineers who were engaged in developing this motor did not take long to realize that one of its serious defects was its large wattless current, i.e. its low power factor. Maurice Leblanc, in 1898, invented a remedy for this in the shape of the Leblanc phase advancer.† This device, which is applicable to slip-ring motors, consists, in its subsequent form, of a statorless d.c. armature which, on being connected through a suitable number of brushes to the slip-rings of the motor and rotated in the same direction as—and faster than—the armature flux, generates an e.m.f. leading the secondary current by 90° and thus improves the power factor of the motor. Other and more effective types known as the Miles Walker series phase advancer and the Scherbius shunt phase advancer were invented later, and all these are now on the market. A still more effective phase advancer, which is chiefly employed when the motor is used as an asynchronous condenser, is the frequency convertor—a statorless armature provided with commutator and brushes at one end and slip-rings and brushes at the other. The convertor, if of the same number of poles as the motor, is coupled to the latter; otherwise it is geared to it. The slip-rings of the convertor are connected through a step-down transformer to the same mains as the motor in such a way that currents of line frequency flowing into it set up a flux rotating against the direction of rotation of the motor. Then an e.m.f. of slip frequency appears at the commutator end and can be injected at any phase into the secondary e.m.f. by connecting the commutator to the motor slip-rings and rocking the brushes. As shown later, this gives rise to improvement in the power factor of the motor. If the rotor of an induction motor is provided with a commutator and brushes, instead of slip-rings, then by connecting the brushes to the mains through a step-down transformer and rocking the brushes, an e.m.f. at any phase to the secondary e.m.f. (which, due to the addition of the commutator, is always of line frequency) can be injected into the secondary, and improvements in the power factor of the motor are obtained as with the frequency convertor.

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* The Papers Committee invite written communications, for consideration with a view to publication, on papers published in the *Journal* without being read at a meeting. Communications (except those from abroad) should reach the Secretary of the Institution not later than one month after publication of the paper to which they relate.

† For a detailed account of the phase advancers mentioned here, see *Journal I.E.E.*, 1931, vol. 69, p. 445.

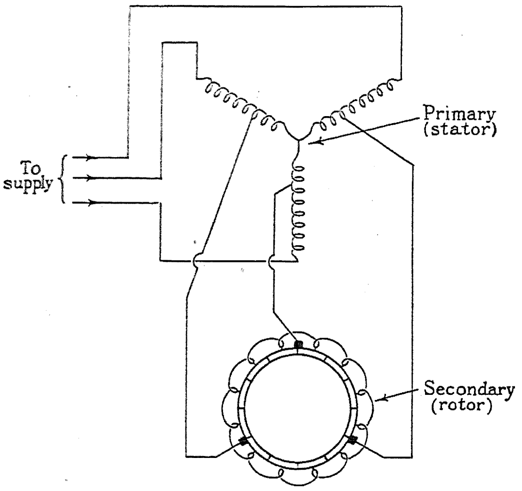

FIG. 1.—Diagram of Heyland motor.

THE HEYLAND MOTOR.

During the last seven years or so induction motors having a phase advancer built into the motor itself, and therefore requiring less material and space than an induction-motor phase-advancer set, have been put upon the market as alternatives to small induction-motor phase-advancer sets or static condenser sets up to about 50 h.p.; in the case of the Osnos motor, dealt with later, this figure has been extended up to about 300 h.p. Certain of these compensated motors have been known for about 30 years, but owing to their cost, which is necessarily higher than that of the ordinary induction motor, and to prejudice against the commutator which they possess, these machines were slow in gaining popularity. Eventually, however, the increasing realization of the necessity and advantages of good power factor, and the satisfactory performance of the phase advancers and polyphase commutator motors already in service, increased the demand for such machines and led not only to the development of the old types but also to the introduction of several new ones. The first purely compensated motor, proposed by Heyland* in 1901, is shown in Fig. 1. Like an ordinary induction motor, it has a stator primary and a rotor secondary, but the latter—instead of being connected to slip-rings—is brought out to a commutator which makes contact with tappings on the primary through three brushes resting 120° apart on the commutator, supposing the motor to have two poles. The motor is thus equivalent to a transformer-type phase-advancer set with a simple commutator induction motor. Its power factor is controlled by rocking the brushes, and maximum compensation occurs when the e.m.f.'s of the tappings lead the brush e.m.f.'s by 90°. Later modifications of the Heyland motor† are:—(*a*) That in which a small auxiliary winding, instead of primary tappings, is employed; (*b*) That in which the secondary is of the squirrel-cage or slip-ring type and the rotor carries an auxiliary commutator winding connected through these brushes to an auxiliary winding on the stator [as in (*a*)], so that the commutator carries only the magnetizing current and not the whole of the secondary current.

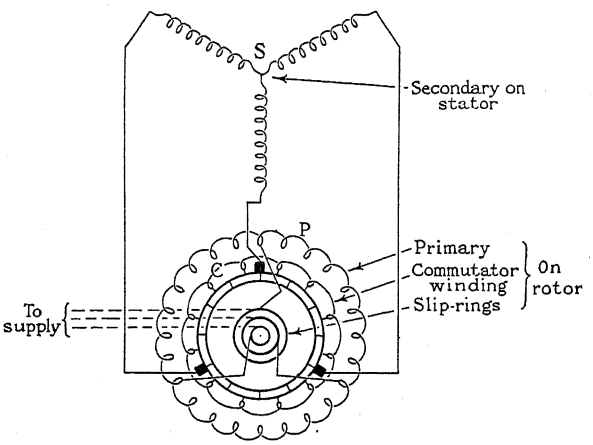

FIG. 2.—Diagram of Osnos motor.

THE OSNOS MOTOR.

This motor, which was described by M. Osnos‡ in 1902, is also known by the trade names "No-Lag" and "Kosfi-Leading" given to it by the British Thomson-Houston Co. and the English Electric Co. respectively. A diagrammatic sketch of a 2-pole motor of this type is given in Fig. 2. Like the induction motor, it has a primary and a secondary, but their positions are reversed. The primary P is on the rotor and is provided with slip-rings. The secondary S is on the stator and is brought out to three terminals. In the same rotor slots as the primary there is a d.c. lap winding C, which is connected to the secondary through three brushes fixed on a movable frame and resting 120° apart on the commutator.

FUNCTION OF THE COMMUTATOR.

Disconnect the secondary from the brushes and impress upon the slip-rings a suitable 3-phase voltage.

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* See *Elektrotechnische Zeitschrift*, 1901, vol. 22, p. 633; or *Electrician*, 1901, vol. 47, p. 627.

† See Bibliography, (1).

‡ *Elektrotechnische Zeitschrift*, 1902, vol. 23, p. 919.

Then a rotating wave of flux will be produced and a voltage of supply frequency will be induced in the secondary and between the brushes.

Let the rotor be revolved against the direction of rotation of the flux; then the magnitude and the frequency of the secondary induced e.m.f. will alter and will be respectively proportional and equal to the difference between the frequencies of rotation of the flux and the rotor. The value of the e.m.f. between any pair of brushes will, however, remain the same as at standstill, because, even though the conductors are revolving, their speed relatively to that of the flux is the same. The frequency of the e.m.f. in each conductor will be equal to that of the supply, but the frequency of the e.m.f. between the brushes will be equal to the difference in the frequencies of rotation of the rotor and the flux, and thus always equal to that of the secondary e.m.f.

Rocking the brushes in a given direction will not alter the value of the voltage between them, but the phase difference between the voltages of a pair of brushes and a secondary phase will depend upon the position in space of the axis of the brushes with respect to the axis of the secondary phase considered, and can be made to have any value from 0 to 2π.

Thus the function of the commutator is to provide a constant e.m.f. the frequency of which is always equal to that of the secondary, and which can have any given phase relation to the secondary e.m.f. The Osnos motor is therefore equivalent to an induction-motor frequency-convertor type of phase-advancer set.

ELEMENTARY CONSIDERATION OF THE ACTION OF THE COMMUTATOR E.M.F.

If the secondary is disconnected from the brushes and short-circuited, and suitable e.m.f.'s are impressed upon the slip-rings, the machine will run like an ordinary induction motor but against the direction of rotation of the flux, i.e. its direction of rotation will be opposite to that of a normal induction motor, and the commutator will possess the properties mentioned above. Let the impressed e.m.f. be increased to the normal value and a load applied to the motor, and let

I_0 = magnetizing current of motor,

the star values of the actual quantities in the secondary circuit being as follows:—

r_2' = resistance of secondary.
I_2' = secondary current.
s = slip of the motor.
E_2 = secondary open-circuit voltage.
kE_2 = commutator voltage induced by the main flux.

Then, neglecting (for simplicity) the iron losses of the motor and the reactance of the secondary, which latter is small, being proportional to the slip, the vector diagram of the secondary will be as shown in Fig. 3, where

OA = I_0 (magnetizing current),
OB = I_2' (secondary current),
OC = $sE_2 = r_2'I_2'$ (slip e.m.f., in phase with secondary current).

Now open-circuit the secondary, connect its terminals to the brushes, and examine the behaviour of the motor with the brushes at different positions in space and the same load on the motor. To get the simplest view of the action of the commutator e.m.f., neglect the reactance, resistance, and ampere-turns of the commutator winding, and consider the following cases:—

(*a*) Suppose the brushes occupy such a position in space that the lead of the brush e.m.f. over the secondary e.m.f. (which will be denoted by the symbol β) is zero. Draw OD = kE_2. Since the load on the motor is the same, we shall still need a current OB in the secondary to produce the necessary torque, and an e.m.f. OC to produce this current. However, as the commutator is now supplying an e.m.f. OD = kE_2 which assists the slip e.m.f., the secondary will only develop an e.m.f.:—

$$DC = OC - CD = sE_2 - kE_2 = (s - k)E_2$$

The slip of the motor will therefore be reduced from s to $(s - k)$; if $k = s$, the slip of the motor will be zero and it will run at synchronous speed; if $k > s$, the slip will be negative and the motor will run at hypersynchronous speed. In neither of these cases, however, will there be any change in the power factor of the motor.

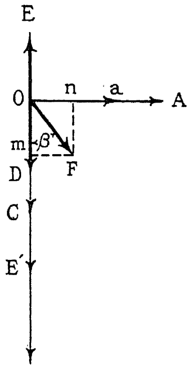

FIG. 3.—Diagram showing action of commutator e.m.f. in Osnos motor.

(*b*) Turn the brushes through 180° so that the brush e.m.f. is OE = kE_2. It now opposes the slip e.m.f., so that the e.m.f. available for producing the current in the secondary is (OC — OE), which is insufficient to send a current OB through the secondary. The secondary will therefore develop an additional e.m.f. CE′ equal to OE, and a total e.m.f.

$$OC + CE' = sE_2 + kE_2 = (s + k)E_2$$

The slip of the motor will increase from s to $(s + k)$, but its power factor will remain the same.

(*c*) Let us now suppose that the brush e.m.f. is OF, leading the slip e.m.f. by an angle DOF. Let Om and On be its components along and at right angles to the slip e.m.f.; then the component Om will reduce the slip of the rotor. But the component On will, assuming the reactance of the secondary circuit to be negligible, send through the secondary a current in phase with itself and therefore in phase with the magnetizing current.

Suppose that this current, reduced to the primary, is equal to Aa; then the motor will only draw a magnetizing current Oa from the line, and consequently its power factor will be improved.

As β is increased, the magnetizing current supplied by the commutator increases and maximum improvement of power factor takes place when $\beta = \pi/2$. This maximum value depends upon the magnitude of the commutator e.m.f. and can be made equal to OA, in which case the motor will draw no magnetizing current from the line; or it may be made greater than OA, in which case the motor will supply magnetizing current to the line. As β is increased beyond $\pi/2$, the power factor deteriorates and the slip of the motor increases owing to the fact that the components of the brush e.m.f. now oppose the secondary e.m.f.

Thus it can be seen that β should not be greater than π, as, if it were, the brush e.m.f. would have a component in phase opposition to OA and would supply a current opposed to the magnetizing current, thus increasing the magnetizing current drawn by the motor from the line.

EQUIVALENT CIRCUIT OF THE OSNOS MOTOR.

By neglecting the reactance of the secondary, and the resistance, reactance, and ampere-turns of the commutator winding, the general idea of the Osnos motor has been arrived at and the feature chiefly responsible for the improvement of the power factor of the latter, i.e. the fact that the component of the commutator e.m.f. leads the secondary e.m.f. by $\pi/2$, has been explained. The quantities that have been neglected, however, exert a considerable effect upon the power factor of the motor. They will therefore be taken into account so as to give a more accurate idea of the motor. To this end, the equivalent circuits of the motor, which enable one to visualize its behaviour at different brush settings, will be obtained.

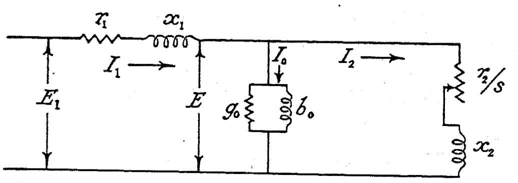

FIG. 4.—Equivalent circuit of ordinary induction motor.

The clue to the equivalent circuit of the Osnos motor lies in a particular interpretation of the resistance and reactance of the secondary in the equivalent circuit of the motor when running with the secondary short-circuited, i.e. as an ordinary induction motor. The equivalent circuit in this case is the well-known one shown in Fig. 4, in which the primary quantities per phase and the star values of the secondary quantities reduced to the primary are:—

E_1 = primary impressed e.m.f.
I_1 = primary current.
r_1 = primary resistance.
x_1 = primary reactance.
g_0 = exciting conductance.
b_0 = exciting susceptance.
$E = I_0/(g_0 - jb_0)$ = e.m.f. consumed by voltage induced in primary by main flux. Therefore $-E$ = secondary induced e.m.f.
I_2 = primary current required to overcome secondary ampere-turns. Therefore $-I_2$ = secondary current.
r_2 = secondary resistance.
x_2 = secondary reactance at full frequency.
s = slip of the motor.

Let

$$k_1 = \frac{\text{primary induced e.m.f. per phase}}{\text{star value of secondary open-circuit e.m.f.}}$$

r_2' = actual resistance per phase of the secondary.
x_2' = actual reactance of the secondary.

Then

$$r_2 = r_2'k_1^2, \quad \text{and} \quad x_2 = x_2'k_1^2.$$

In the circuit of Fig. 4,

Equivalent resistance of secondary

$$= r_2/s$$
$$= r_2' \,.\, k_1^2/s$$
$$= r_2'(k_1/s) \div (1/k_1)$$

where, it should be observed,

$$\frac{k_1}{s} = \frac{\text{primary induced e.m.f.}}{\text{secondary induced e.m.f.}} \text{ at all loads}$$
$$= \text{true ratio of transformation of voltage}$$
$$\frac{1}{k_1} = \frac{\text{primary current required to overcome secondary ampere-turns}}{\text{actual secondary current}} \text{ at all loads}$$
$$= \text{true ratio of transformation of current}$$

Expressing the equivalent resistance as r_2/s or $r_2'k_1^2/s$ does not give any idea of the steps in the transformation of the actual resistance of the secondary; on the other hand, expressing it as $r_2'(k_1/s) \div (1/k_1)$ gives a correct view of the steps in the transformation and shows that the equivalent resistance is equal to the actual resistance multiplied by the ratio of transformation of voltage and divided by the ratio of transformation of current. From this analysis of the equivalent resistance one can determine the latter under various conditions as shown below.

(a) Let the rotor of the motor be locked and its secondary loaded as the secondary of a transformer. Then

Ratio of transformation of voltage = k_1
Ratio of transformation of current = $1/k_1$

∴ Equivalent resistance of secondary

$$= (r_2'k_1) \div (1/k_1)$$
$$= r_2'k_1^2$$
$$= r_2$$

(*b*) Now suppose the machine to be running with a slip s as an Osnos motor, and that the commutator e.m.f. is in phase with the secondary e.m.f. and has a value kE_2. Then

E.M.F. developed by secondary $= sE_2$

Total e.m.f. producing the current in secondary

$$= (sE_2 + kE_2)$$
$$= (s + k)E_2$$

Ratio of transformation of voltage $= \dfrac{E}{(s + k)E_2} = \dfrac{k_1}{(s + k)}$

Effect of Commutator Ampere-Turns.

In the elementary consideration of the Osnos motor the effect of the ampere-turns of the commutator winding was neglected. This will now be taken into consideration. The commutator ampere-turns are k times the secondary ampere-turns, and, being in phase with the latter, are in this case added to them; so that with a certain current, $(1 + k)$ times the secondary ampere-turns are now produced. Therefore the ratio of transformation of current is no longer $1/k_1$ but is $(1 + k)$ times $1/k_1$, or $(1 + k)/k_1$. Hence

Equivalent resistance of secondary

$$= r'_2 \frac{k_1}{s + k} \div \frac{1 + k}{k_1}$$
$$= \frac{r'_2 k_1^2}{(s + k)(1 + k)}$$
$$= \frac{r_2}{(s + k)(1 + k)}$$

The equivalent reactance of the secondary of an ordinary induction motor

$$= x_2$$
$$= x'_2 k_1^2$$
$$= sx'_2 \frac{k_1}{s} \div \frac{1}{k_1}$$

That is, like the equivalent resistance, it is equal to the actual secondary reactance multiplied by the ratio of transformation of voltage and divided by the ratio of transformation of current. Therefore

Equivalent reactance of the secondary of the Osnos motor

$$= sx'_2 \frac{k_1}{s + k} \div \frac{1 + k}{k_1}$$
$$= \frac{sx'_2 k_1^2}{(s + k)(1 + k)}$$
$$= \frac{sx_2}{(s + k)(1 + k)}$$

The equivalent resistance of the commutator winding can be obtained in the same way as that of the secondary, but its equivalent reactance, as well as that of the primary, present some difficulties owing to the leakage flux of both the windings being linked with each. We shall defer consideration of them, and for the present assume the total impedance of the commutator winding and the effect of the leakage flux of this winding upon the primary to be negligible; so that the reactance drop in the primary is due to I_1 and is $x_1 I_1$, as in an ordinary induction motor.

Resistance drop in primary $= r_1 I_1$

E.M.F. consumed by exciting impedance of primary

$$= E$$
$$= \frac{I_0}{(g_0 - jb_0)}$$

Hence, as shown in Fig. 5, the primary side of the equivalent circuit of the Osnos motor for $\beta = 0$ is the same as in an ordinary induction motor, but the secondary side, for the reasons given above, carries a current $(1 + k)I_2$ and consists of a resistance $r_2/[(s + k)(1 + k)]$ and a reactance $sx_2/[(s + k)(1 + k)]$.

Corrections to be Applied to Circuit of Fig. 5.

The current and ampere-turns equation of the Osnos motor is

$$I_1 = I_0 + (1 + k)I_2 \quad . \quad . \quad . \quad . \quad (1)$$

The primary is linked with the leakage flux due to a current I_1 in the primary and a current in the commutator winding, which, when reduced to the primary, is $-kI_2$. Therefore

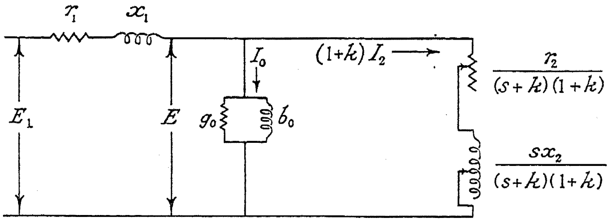

FIG. 5.—Equivalent circuit of Osnos motor for $\beta = 0$, neglecting impedance of commutator winding.

Leakage-reactance drop in primary $= x_1(I_1 - kI_2)$

This reactance drop is a function of I_1 and I_2, and as the primary carries a current I_1 it is difficult to show this in the equivalent circuit. However, with the help of equation (1) it can be expressed approximately as a function of I_1 only, as shown below.

By substituting for I_2 from (1),

$$jx_1(I_1 - kI_2) = jx_1 \left[I_1 - \frac{k(I_1 - I_0)}{1 + k} \right]$$
$$= jx_1 \frac{I_1 + kI_0}{1 + k}$$
$$= j\frac{x_1}{1 + k} I_1 \text{ (neglecting } kI_0\text{)}$$

From the form of the last expression it will be seen that the e.m.f. induced in the primary of reactance x_1 by a current $(I_1 - kI_2)$ is approximately equal to the e.m.f. induced in the primary of reactance $x_1/(1 + k)$ by a current I_1. Hence it may be said that the effect of the leakage flux of the commutator winding is equivalent to a change in the reactance of the primary from x_1 to $x_1/(1+k)$.

Reactance drop of commutator winding reduced to primary $= jk[x_1(I_1 - kI_2)]$

To show this reactance drop in the secondary, it should be expressed as a function of I_2. This is done by substituting for I_1 from (1), which gives

$$jkx_1(I_1 - kI_2) = jkx_1[I_0 + (1+k)I_2 - kI_2]$$
$$= jkx_1(I_0 + I_2)$$
$$= jkx_1 I_2 \text{ (neglecting } I_0\text{, to avoid complications)}$$

Hence, remembering that the secondary current reduced to primary is $-I_2$,

Reactance of commutator winding reduced to primary

$$= -kx_1$$

Equivalent reactance of commutator winding

$$= -\frac{kx_1}{(s+k)(1+k)}$$

If r_a denotes the star value of the resistance of the commutator winding reduced to primary,

Equivalent resistance of commutator winding

$$= \frac{r_a}{(s+k)(1+k)}$$

Therefore

Total equivalent reactance of secondary and commutator winding

$$= \frac{sx_2}{(s+k)(1+k)} - \frac{kx_1}{(s+k)(1+k)}$$
$$= \frac{sx_2 - kx_1}{(s+k)(1+k)}$$

Total equivalent resistance of secondary and commutator winding

$$= \frac{r_2}{(s+k)(1+k)} + \frac{r_a}{(s+k)(1+k)}$$
$$= \frac{r_2 + r_a}{(s+k)(1+k)}$$
$$= \frac{R_2}{(s+k)(1+k)} \text{ (by putting } r_2 + r_a = R_2)$$

and the equivalent circuit of the Osnos motor is as shown in Fig. 6.

Equivalent Circuit for Any Value of β.

Let the commutator e.m.f. lead the secondary e.m.f. by an angle which may have any value from 0 to 2π. Then, remembering that the secondary e.m.f. is $-E$,

Component of commutator e.m.f. in phase with secondary e.m.f.

$$= (-k\cos\beta)E$$
$$= -mE \text{ (putting } k\cos\beta = m)$$

Component of commutator e.m.f. at right angles to secondary e.m.f.

$$= -(jk\sin\beta)E$$
$$= -jnE \text{ (putting } k\sin\beta = n)$$

Total e.m.f. in phase with secondary e.m.f.

$$= -(s+m)E$$

Considering only the e.m.f. $-(s+m)E$ and the current produced by it, the equivalent circuit is as shown in Fig. 7 (excluding the shunt circuit that is not connected) and is obtained by putting m for k in Fig. 6.

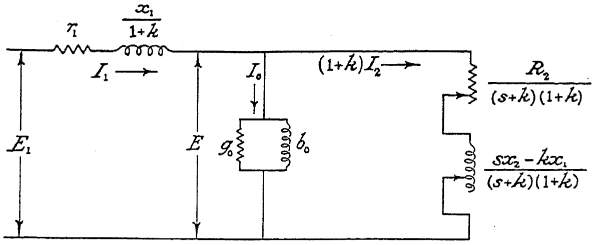

FIG. 6.—Equivalent circuit of Osnos motor, considering impedance of commutator winding.

To examine in a simple way the action of the remaining commutator e.m.f. ($-jnE$), the reactance of the secondary circuit, which is very small compared with its resistance, may be neglected. Then, as long as n is positive, i.e. β lies between 0 and π, this e.m.f. will send a current nE/R_2 leading the secondary e.m.f. by 90°, or, in other words, it will supply wattless magnetizing current. Hence

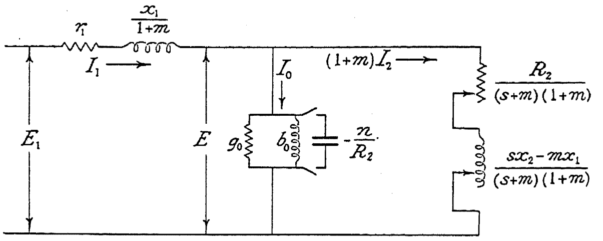

FIG. 7.—Equivalent circuit of Osnos motor for any value of β.

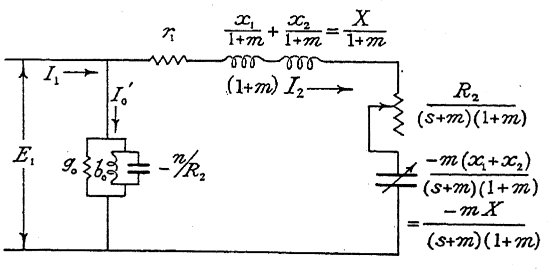
r_1
$\frac{x_1}{1+m}+\frac{x_2}{1+m}=\frac{X}{1+m}$
I_1
I_0'
$(1+m)I_2$
$\frac{R_2}{(s+m)(1+m)}$
E_1
g_0
b_0
$-n/R_2$
$\frac{-m(x_1+x_2)}{(s+m)(1+m)}$
$=\frac{-mX}{(s+m)(1+m)}$

FIG. 8.—Simplified equivalent circuit of Osnos motor.

Wattless magnetizing current drawn by the motor from the line

$$= b_0E - nE/R_2$$
$$= (b_0 - n/R_2)E$$

Thus the exciting susceptance of the motor will be altered from b_0 to $(b_0 - n/R_2)$. The action of this e.m.f. can therefore be shown in the equivalent circuit by connecting a condensive susceptance $- n/R_2$ in parallel with the exciting susceptance, as shown in Fig. 7.

Simplification of Circuit of Fig. 7.

Reactance of secondary circuit

$$= \frac{sx_2 - mx_1}{(s+m)(1+m)}$$

$$= \frac{x_2}{1+m} - \frac{m(x_1 + x_2)}{(s+m)(1+m)}$$

$$= \frac{x_2}{1+m} - \frac{mX}{(s+m)(1+m)} \quad (\text{where } X = x_1 + x_2)$$

Shifting the new exciting circuit to one end (as is done in the circuit of an ordinary induction motor) and grouping the constant part of the reactance of the secondary circuit, $x_2/(1+m)$, with the primary reactance, the circuit of Fig. 7 may be replaced by that of Fig. 8, the latter being very much the easier to treat.

CHARACTERISTICS OF THE OSNOS MOTOR.

No-load Characteristics.

The most important part of the circuit of Fig. 8 is the shunt circuit. The current flowing through it is approximately equal to the no-load current of the motor. When $m = n = 0$, i.e. the motor is running as an ordinary induction motor, the wattless lagging current in the shunt circuit is equal to b_0E_1 and is the root cause of the low power factor of the motor. It will now be seen, therefore, that the commutator of the Osnos motor removes this root cause, and that with suitable values of n the wattless lagging current in the shunt circuit can be reduced, eliminated, or made leading. When $m = 0$, $n = k$; and the improvement in the power factor of the shunt circuit—and therefore in the no-load power factor of the motor—is a maximum. The wattless current in the shunt circuit in this case is $(b_0 - k/R_2)E_1$, and if k is such that $k/R_2 = 2b_0$ the shunt circuit will supply as much wattless current to the line as it took in the case of an ordinary induction motor. Since g_0 is constant, the no-load current of the motor will be as much leading as it was lagging when the machine was running as an ordinary induction motor. From a study of the data relating to various sizes of the British Thomson-Houston Co.'s "No-Lag" (Osnos) motors it has been found that to obtain as much leading current on no load as the machine takes when running as an ordinary induction motor, the e.m.f. required from the commutator is about 2 per cent of the secondary open-circuit e.m.f. for large motors, to about 10 per cent for very small motors.

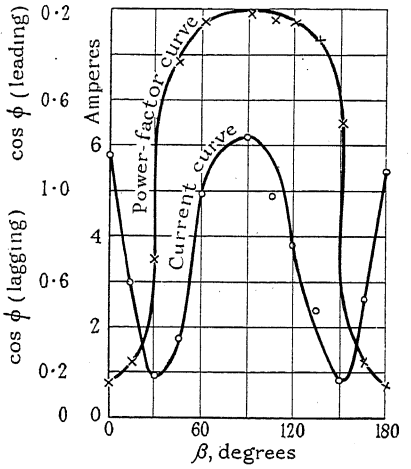

FIG. 9.—Curves showing variation with β of no-load current and power factor of 17·5-h.p. "No-Lag" motor.

The curves shown in Fig. 9 give the no-load current and power factor of a 17·5-h.p. "No-Lag" motor for various values of β from 0 to π. If β lies between π and 2π, n will be negative. Therefore the wattless lagging current in the shunt circuit will be greater than b_0E_1, and the power factor of the machine will be worse than that of an ordinary induction motor.

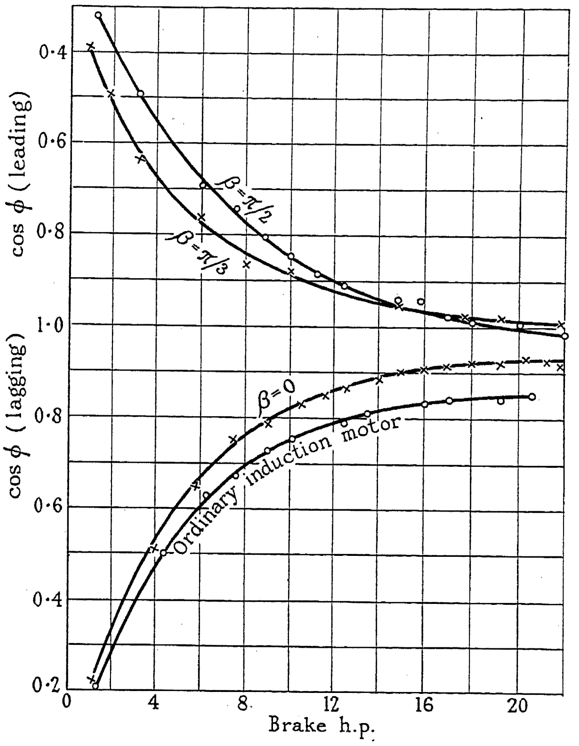

FIG. 10.—Curves showing power factor of 17·5-h.p. "No-Lag" motor for various values of β from 0 to $\pi/2$, and as an ordinary induction motor.

Load Characteristics.

Fig. 10 shows the power-factor characteristics of a 17·5-h.p. British Thomson-Houston "No-Lag" motor for various values of β from 0 to $\pi/2$, and also when working as an ordinary induction motor.

When $\beta = 0$, $n = 0$ and $m = k$. The conductance and susceptance of the shunt circuit, and therefore the no-load power factor of the motor, are the same as in an ordinary induction motor. The reactances in the rest of the circuit, which will be called the main circuit, are x_1 and x_2 in an ordinary induction motor; it will be seen that when $\beta = 0$ these reactances are not only reduced to $x_1/(1 + k)$ and $x_2/(1 + k)$ respectively, but a capacitance $-k(x_1 + x_2)/[(s + k)(1 + k)]$ is added. Hence when $\beta = 0$ the power factor of the main circuit, and consequently of the motor, is better than that of an ordinary induction motor.

When β lies between 0 and $\pi/2$ there is improvement in the power factor of both the shunt and the main circuits, but the net improvement of power factor is chiefly due to the former. When $\beta = \pi/2$, $m = 0$ and $n = k$, and the power factor of the main circuit is the same as for an ordinary induction motor, but there is maximum improvement in the power factor of the shunt circuit; owing to the latter the net improvement in the power factor of the motor is generally a maximum —but not at all loads, as will be seen on examining the curves for $\beta = \pi/2$ and $\beta = \pi/3$ in Fig. 10.

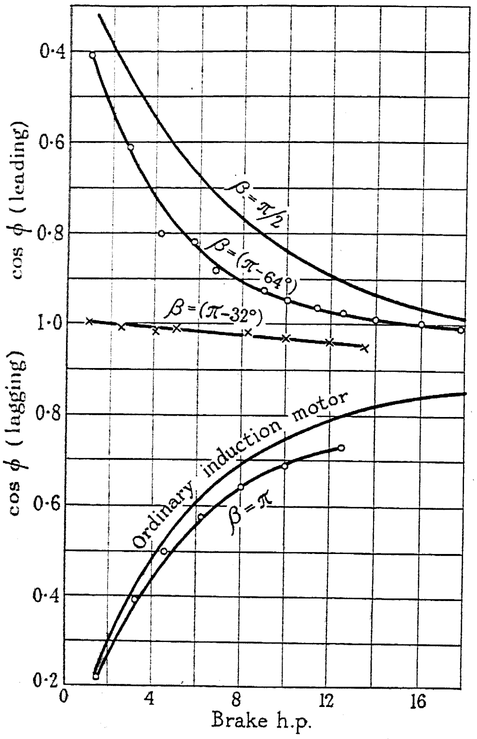

FIG. 11.—Curves showing power factor of 17·5-h.p. " No-Lag " motor for various values of β between $\pi/2$ and π, and when run as ordinary induction motor.

The curves of Fig. 11 show the power factor of the motor for values of β from $\pi/2$ to π. When β lies between $\pi/2$ and π, n is positive but m is negative. The power factor of the main circuit is worse than that of an induction motor, since $x_1/(1 + m)$ and $x_2/(1 + m)$ are now greater than x_1 and x_2 respectively, and $-m(x_1 + x)/[(s + m)(1 + m)]$ is no longer a capacitance but is a reactance. However, if n is large enough there will be a considerable improvement in the power factor of the motor. It should be observed that although n has the same value for, say, $\beta = \theta$ (where θ is less than $\pi/2$) and $\beta = (\pi - \theta)$, there is greater improvement of power factor in the first case owing to the reasons already given. From what has been said it follows that when $\beta = \pi$ the power factor of the motor is worse than that of an ordinary induction motor.

Current Characteristics.

Two objects of improving the power factor of an induction motor are to reduce the kVA and therefore the current taken by it, and, where possible, to make it supply leading kVA so as to compensate for the lagging kVA of some other motor. That the Osnos motor can do both is shown by the curves of Fig. 12, which give the current taken by a 17·5-h.p. " No-Lag " motor when $\beta = \pi/2$ and it is running as an ordinary induction motor, and also the wattless kVA supplied to or taken from the line in each case.

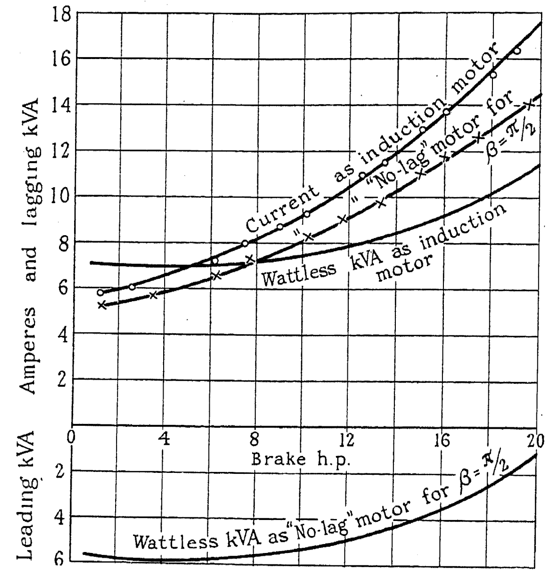

FIG. 12.—Curves showing current and wattless kVA of 17·5-h.p. " No-Lag " motor when run as an ordinary induction motor, and when $\beta = \pi/2$.

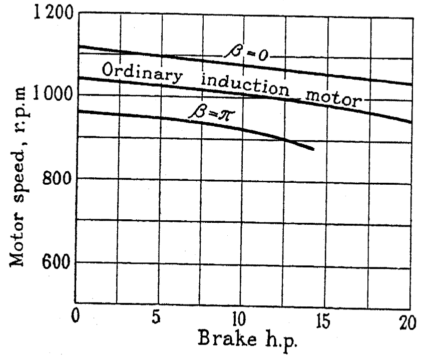

FIG. 13.—Speed characteristics of 17·5-h.p. " No-Lag " motor.

Speed Curves.

Fig. 13 shows the speeds at various loads of a 17·5-h.p. " No-Lag " machine run as an ordinary induction motor, and when $\beta = 0$ and $\beta = \pi$. For $\beta = \pi/2$ the speed curve is very much the same as the middle curve. For values of β between 0 and $\pi/2$, the speed curves lie above this, and for values of β between $\pi/2$ and π they lie below it.

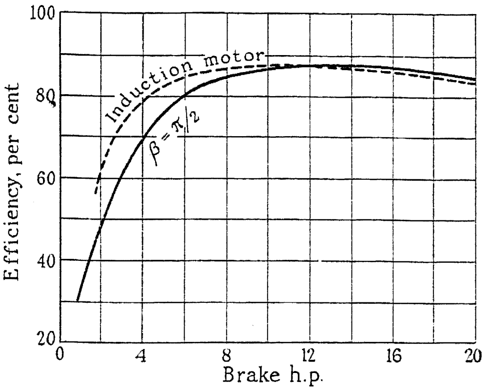

FIG. 14.—Curves showing efficiency of 17·5-h.p. "No-Lag" motor for $\beta = \pi/2$ and when run as an ordinary induction motor.

Efficiency Curves.

The curves of Fig. 14 show the efficiency of a 17·5-h.p. "No-Lag" motor run as an ordinary induction motor and when $\beta = \pi/2$, i.e. when the compensating effect of the commutator e.m.f. is a maximum.

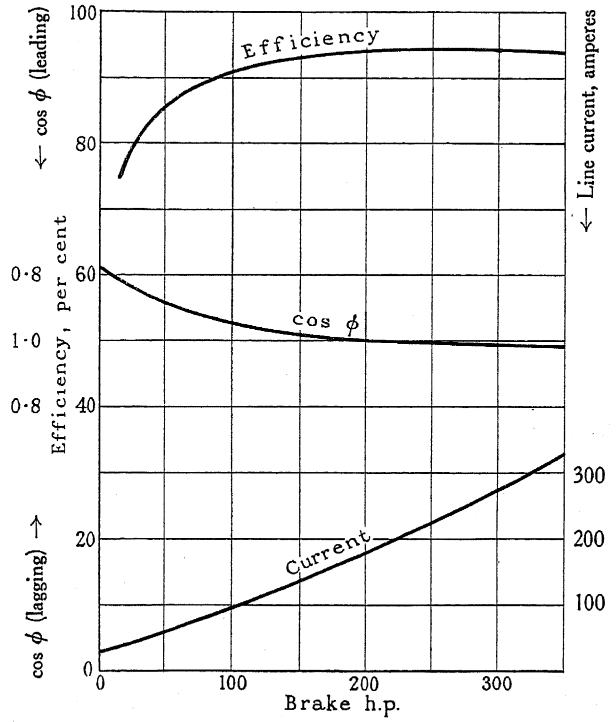

FIG. 15.—Curves showing power factor and efficiency of 250-h.p. "No-Lag" motor.

Curves of a 250-h.p. "No-Lag" Motor.

The "No-Lag" motor on which the above tests were made is a small machine, one of the first of its type built by the British Thomson-Houston Co. Fig. 15 shows the current, power factor, and efficiency curves of a 250-h.p. 500-volt 50-cycle 6-pole 3-phase "No-Lag" motor of recent design.

CURRENT LOCI OF THE OSNOS MOTOR.

Owing chiefly to the contact resistance of a brush, R_2 is not constant but varies with the current, as shown in Fig. 16. This is the chief obstacle in the way of getting a correct solution of the circuit of Fig. 8. A simple solution, without appreciable sacrifice in accuracy, can, however, be obtained by assuming for R_2 an average value, as shown below. For instance, one would like to know with a fair amount of accuracy the behaviour of the motor under test between a light load—corresponding to 5 amperes—and 25 per cent overload, for which the secondary current would be in the neighbourhood of 20 amperes. We may therefore assume for R_2 a constant value 2·70 ohms, which is the mean of its values at 5 and 20 amperes respectively. Then for any particular brush setting the current through the shunt circuit will be constant and approximately equal to the no-load current of the motor. As in Fig. 17, let O′x′ and O′y′ be the axes of x and y.

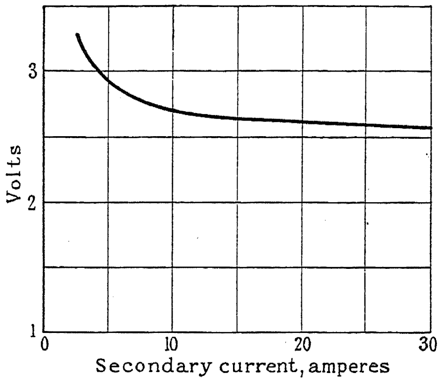

FIG. 16.—Curves showing variation, with current, of resistance of secondary circuit of 17·5-h.p. "No-Lag" motor.

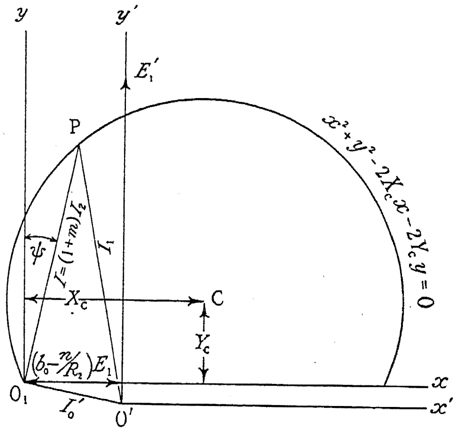

FIG. 17.—Diagram showing construction of current locus of Osnos motor.

$O'E_1' = E_1$ (primary impressed e.m.f.),

$O'O_1 = I_0'$ (current in shunt circuit, i.e. approximate no-load current of motor),

$O_1P = I = (1 + m)I_2$ (current in main circuit),

$O'P = I_1$ (primary current),

(x_n, y_n) = co-ordinates of O_1, the extremity of the vector representing the current in the shunt circuit.

Then

$$x_n = (b_0 - n/R_2)E_1 \quad . \quad . \quad . \quad . \quad (2)$$

$$y_n = g_0 E_1 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

Since I_0' is constant, the locus of the extremity of the primary current (I_1) vector is the same as the locus of the extremity of the vector representing I, the current in the main circuit.

An induction motor connected to a phase advancer,[*] and several types of commutator induction motors, can be represented by a circuit such as that shown in Fig. 8. That is to say, each of these has an equivalent circuit which is composed of:—

(a) A shunt circuit of constant admittance.

(b) A main circuit consisting of the following in series:—

(i) A constant resistance, such as r_1.
(ii) A constant reactance, such as $X/(1 + m)$.
(iii) A variable resistance, such as $R_2/[(s+m)(1+m)]$.
(iv) A variable reactance, such as $-mX/[(s+m)(1+m)]$.

It is shown in the Appendix that if a constant e.m.f. (E_1) is impressed on such a circuit, the locus of the current in it is a circle, provided the ratio of the variable reactance to variable resistance of the main circuit is constant. The equation of this circle, referred to O (the extremity of the constant current vector in the shunt circuit) as origin, and O_1x and O_1y (parallel to $O'x'$ and $O'y'$ in Fig. 17) as axes, is

$$x^2 + y^2 - 2X_c x - 2Y_c y = 0 \quad . \quad . \quad . \quad . \quad (4)$$

where X_c, Y_c, the co-ordinates of the centre, are given by

$$X_c = \frac{\text{half the impressed e.m.f.}}{\text{constant reactance}\left(1 - \dfrac{\text{constant resistance}}{\text{constant reactance}} \times \dfrac{\text{variable reactance}}{\text{variable resistance}}\right)}$$

$$= \frac{\frac{1}{2}E_1}{\dfrac{X}{1+m}\left[1 + \dfrac{r_1}{X/(1+m)}\dfrac{mX}{R_2}\right]} = \frac{E_1(1+m)}{2X\left[1 + \dfrac{r_1 m(1+m)}{R_2}\right]} \quad . \quad . \quad . \quad (5)$$

$$Y_c = -X_c \frac{\text{variable reactance}}{\text{variable resistance}}$$

$$= X_c \frac{mX}{R_2} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (6)$$

In the Osnos motor, the ratio of the variable reactance to the variable resistance of the main circuit is mX/R_2 and is constant, since R_2 has been assumed to be constant. Hence the current locus is a circle through O_1 of centre (X_c, Y_c).

An obvious way of simplifying equation (5) is to neglect the term $r_1 m(1 + m)/R_2$, which is very small. Greater and more accurate simplification is, however, obtained by making use of the following considerations:—

In an ordinary induction motor r_2 is usually taken equal to r_1. In the term $r_1 m(1 + m)/R_2$, which is very small and in which m is positive or negative according to whether the value of β lies between 0 and $\pi/2$ or between $\pi/2$ and π, we may take

$$R_2 = r_2(1 + m) = r_1(1 + m)$$

where m in this case is always positive. Then, when the value of β lies between 0 and $\pi/2$, the denominator of (5)

$$= 2X\left[1 + \frac{r_1 m(1+m)}{R_2}\right]$$

$$= 2X\left[1 + \frac{r_1 m(1+m)}{r_1(1+m)}\right]$$

$$= 2X(1 + m)$$

When the value of β lies between $\pi/2$ and π, m is negative, and the denominator

$$= 2X\left[1 + \frac{r_1 m(1+m)}{R_2}\right]$$

$$= 2X\left[1 - \frac{r_1 m(1-m)}{r_1(1+m)}\right]$$

$$= 2X[1 - m + 2m^2/(1+m)]$$

$$= 2X(1 - m) \text{ (neglecting the term involving } m^2\text{)}$$

Hence in either case X_c becomes simplified to $E_1/2X$, and the simplified co-ordinates of the centre, which will be denoted by (x_c, y_c) to distinguish them from the previous values, are given by the following expressions.

$$x_c = E_1/2X = \gamma \quad . \quad . \quad . \quad . \quad . \quad (7)$$

$$y_c = x_c(mX/R_2) = mE_1/2R_2 = k\cos\beta E_1/2R_2 = \delta\cos\beta \quad (8)$$

where $\delta = kE_1/2R_2 = \text{constant}$

Applications of the Theory.

The constants of a 17·5-h.p. British Thomson-Houston "No-Lag" motor, delta-connected in the primary and star-connected in the secondary, are:—

Ratio of primary e.m.f. per phase to star value of secondary open-circuit e.m.f. (k_1) = 3·38.
Frequency of supply (f) = 51·7.[*]
Primary impressed e.m.f. (E_1) = 416 volts.
Exciting susceptance (b_0) = 0·013 mho.
Exciting conductance (g_0) = 0·0018 mho.
Primary resistance (r_1) = 1·78 ohms.
Sum of primary and secondary leakage reactances (X) = 8 ohms.
Brush contact-drop (unreduced) = 0·6 volt.

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[*] See *Journal I.E.E.*, 1931, vol. 69, p. 445.

[*] This frequency was used instead of 50, the normal frequency for the motor, in order to get a suitable output from the generator coupled to it when for values of β between $\pi/2$ and π the speed of the motor fell considerably below that of synchronism.

Brush contact-drop (reduced to primary) = $2 \cdot 03$ volts.

Resistance of secondary, commutator winding, and brush contact = $2 \cdot 52 + 2 \cdot 03/I_2$ ohms.

Ratio of commutator e.m.f. to secondary open-circuit e.m.f. (k) = $0 \cdot 067$.

The current loci of a 17·5-h.p. "No-Lag" motor when running as an ordinary induction motor and for various values of β from 0 to 2π, are shown as the undotted curves in Fig. 18. They can be constructed, with the help of equations (2), (3), (7), (8), and the data given above, as follows:—

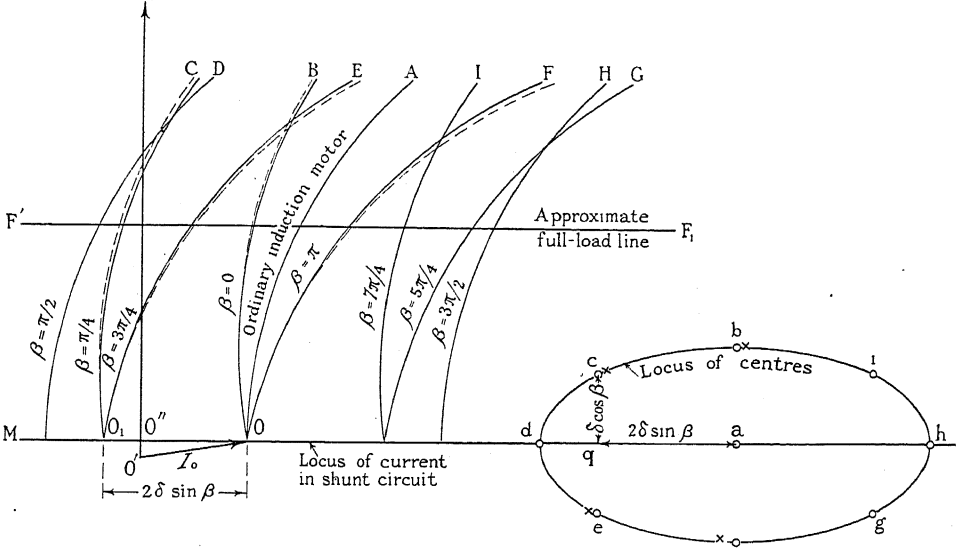


FIG. 18.—Theoretical current loci of 17·5-h.p. "No-Lag" motor.
Scale: 1 cm = 4 amperes.

Let $O'E_1'$ represent the direction of the primary impressed e.m.f. Draw the magnetizing-current vector $O'O = I_0 = 5 \cdot 45$ amperes, inclined at an angle arc cos $0 \cdot 14$ to OE_1'. Through O draw MOh cutting $O'E_1'$ at O″. Then MOh will be the locus of the extremity of the current in the shunt circuit for various values of β. Mark off $Oa = x_c = 26$ amperes. Then the circle through O of centre "a" is the current locus of the machine when running as an ordinary induction motor. To find the primary current locus for any value of β, say $\pi/4$, mark off $O''O_1 = (b_0 - n/R_2)E_1 = -2 \cdot 0$ amperes. Now mark off $O_1q = x_c = 26$ amperes, and from the perpendicular at "q" mark off "qc" $= y_c = 3 \cdot 7$ amperes. Then the circle through O_1 of centre "c" will be the current locus for $\beta = \pi/4$; and so on for other values of β. It will be seen from these loci that although for values of β such as $\pi/4$, and $(\pi - \pi/4)$ or $3\pi/4$, the no-load current is the same, the behaviour of the motor is much better in the former case. It will also be noticed that β should not be greater than π.

Using equations (5) and (6) instead of equations (7) and (8), the current loci will be the dotted circles, with centres indicated by crosses. Assuming the full-load efficiency of the motor to be the same at all brush settings, and drawing the full-load line as shown, it will be seen that within working limits there is very little difference between the dotted and the undotted loci.

Another interesting and useful way of constructing the current loci for various values of β is obtained from the following considerations. Let the current locus for any value of β, constructed as explained above, be the circle through O_1 of centre "c" in Fig. 18. Then since $O''O = b_0E_1$, and $O''O_1 = (b_0 - n/R_2)E_1$, therefore

$$OO_1 = -nE_1/R_2 = -\sin \beta k E_1/R_2 = -2\delta \sin \beta.$$

Since $O_1q = \gamma = Oa$; $Oq = \gamma - nE_1/R_2$; and "aq" $= -nE_1/R_2 = -2\delta \sin \beta$: therefore, to construct the locus for any value of β:—

(a) Mark off along aO lengths OO_1 and "aq" each equal to $-2\delta \sin \beta$, from O and "a" respectively.

(b) From the perpendicular at "q" mark off "qc" $= \delta \cos \beta$.

Then the circle through O_1 of centre "c" will be the current locus.

Locus of Centres.

The centres of the current circles for various values of β lie on an ellipse. To prove this, with "a" (the centre of the induction-motor circle) as origin let (x, y) be the co-ordinates of the centre of the current circle for any value of β. Then

$$x = -2\delta \sin \beta = -2\delta\sqrt{(1 - \cos^2 \beta)} \quad . \quad . \quad (9)$$

$$y = \delta \cos \beta \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (10)$$

Substituting for $\cos \beta$ from (10) in (9),

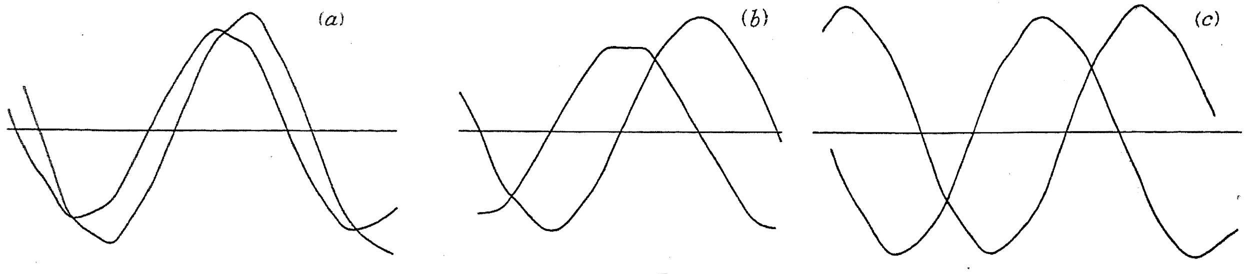
$$x = -2\delta\sqrt{(1 - y^2/\delta^2)}$$

Squaring both sides of this equation,

$$x^2 = 4\delta^2(1 - y^2/\delta^2)$$

or

$$\frac{x^2}{4\delta^2} + \frac{y^2}{\delta^2} = 1 \quad . \quad . \quad . \quad . \quad . \quad (11)$$



$\beta = 32°$ $\beta = \frac{\pi}{2}$ $\beta = (\pi - 64°)$

FIG. 19.—Oscillograms of secondary and commutator voltage waves of 17·5-h.p. "No-Lag" motor.

Equation (11) represents the locus of centres, an ellipse whose major and minor axes ("dah" and "baf") are respectively equal to 2δ and δ.

Verification of Theory.

Oscillograms of the commutator and secondary-voltage waves were photographed with a shooting-plate camera and also traced on oil paper, so as to enable the phase relation between them to be accurately measured. Some of these, prepared from photographs, are shown in Fig. 19, (*a*), (*b*), and (*c*).

Fig. 20 shows the theoretical current loci of a 17·5-h.p. British Thomson-Houston "No-Lag" motor for values of β from 0 to $\pi/2$ (marked against the loci), obtained from the oscillograms mentioned above. The experimental current loci are obtained by joining the points of the same kind on or near the theoretical loci. The current locus of the motor when running as an ordinary induction motor, and experimental points on this locus, are also shown.

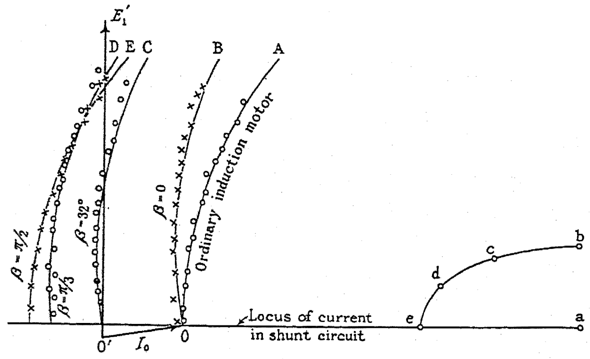


FIG. 20.—Theoretical current loci of 17·5-h.p. "No-Lag" motor for values of β between 0 and $\pi/2$.

Scale: 1 cm = 4·6 amperes.

Fig. 21 shows the theoretical loci of the motor for the values of β between $\pi/2$ and π marked against the loci. The experimental current loci are obtained by joining the points on or near the theoretical loci.

Geometry of the Circle Diagram.

The usual methods employed for obtaining the output, torque, etc., from the circle diagram of an ordinary induction motor are not applicable to the Osnos motor. The following general method of treating the circle diagram can be used for any motor and is an adaptation of that suggested by Prof. Miles Walker.*

As in Fig. 22, let:—

$O'E_1'$ be the direction of the impressed e.m.f.
$O'O_1$ be the constant current in the shunt circuit.
O_1x and O_1y be the axes of x and y.
O_1PL be the circle diagram.
(x_c, y_c) be the co-ordinates of the centre C of the circle referred to O_1 as origin.
$O_1P = I$ (current in main circuit).
$O'P = I_1$ (primary current).
(x', y') = co-ordinates of P referred to O_1 as origin.

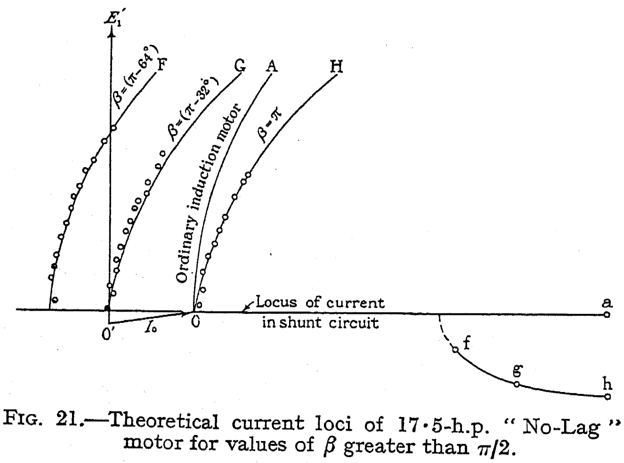


FIG. 21.—Theoretical current loci of 17·5-h.p. "No-Lag" motor for values of β greater than $\pi/2$.

Scale: 1 cm = 5 amperes.

Then the equation of the circle is

$$x^2 + y^2 - 2(x_c x + y_c y) = 0$$

Since P lies on this circle, we have

$$x'^2 + y'^2 - 2(x_c x' + y_c y') = 0$$

Putting

$$x'^2 + y'^2 = I^2$$

gives

$$I^2 = 2(x_c x' + y_c y') \quad . \quad . \quad . \quad . \quad (12)$$

---

* "The Control of the Speed and Power Factor of Induction Motors," 1924 (Benn), chap. 2.

The treatment set out below makes use of the following relation between the equation of a line and the perpendicular to it from any point.

If $Ax + By = 0$ is the equation of a straight line, and P denotes the length of the perpendicular to this line from any point (x', y'), then

$$P = Ax' + By'/\sqrt{(A^2 + B^2)}$$

Whence

$$Ax' + By' = CP \quad . \quad . \quad . \quad . \quad . \quad (13)$$

where $C = \sqrt{(A^2 + B^2)} = \text{constant}$

Substituting for I from (12),

$$\text{Output per phase} = y'E_1 - 2R(x_c x' + y_c y')$$

$$= 2R\left\{\left[(E_1/2R) - y_c\right]y' - x_c x'\right\}$$

$$= 2RC_L P_L \text{ watts}$$

where $C_L = \sqrt{\left\{\left[(E_1/2R) - y\right]^2 + x_c^2\right\}}$

P_L = amperes represented by the length of the perpendicular from (x', y') to the line:—

$$\left[(E_1/2R) - y_c\right]y - x_c x = 0 \quad . \quad . \quad . \quad (15)$$

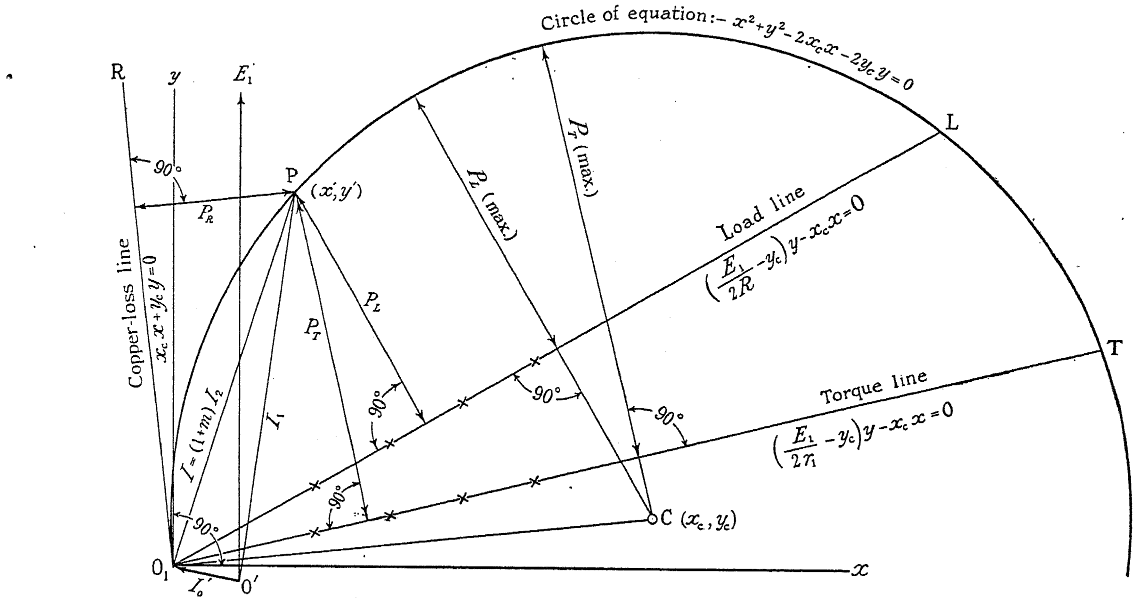


FIG. 22.—Diagram showing method of obtaining load, torque, etc., from the circle diagram of a motor.
Scale: 1 cm = 4 amperes.

Copper Loss.

Let R be the total resistance of the main circuit.

Then copper loss in main circuit

$$= RI^2$$

$$= 2R(x_c x' + y_c y') \ \left[\text{by equation (12)}\right]$$

$$= 2RC_R P_R \text{ watts } \left[\text{by equation (13)}\right]$$

where $C_R = \sqrt{(x_c^2 + y_c^2)} = \text{constant}$

P_R = amperes represented by the length of the perpendicular from (x', y') to the line whose equation is:—

$$x_c x + y_c y = 0 \quad . \quad . \quad . \quad . \quad . \quad (14)$$

Hence the copper loss in the main circuit is proportional to the perpendicular from (x', y') to the line given by equation (14). This line, shown as O_1R in Fig. 22, can be called the "copper-loss line"; it is easily drawn, as it is perpendicular to O_1C, the line joining the origin to the centre of the circle.

Output or Load Line.

The output per phase of the motor is equal to the input to the motor minus the copper loss in the main circuit. Therefore

$$\text{Output per phase} = y'E_1 - RI^2$$

The output per phase of the motor is therefore proportional to the length of the perpendicular from (x', y') to the line given by (15). The latter, shown as O_1L in Fig. 22, may be called the "load line." The most convenient way of drawing this line is to obtain a few points on it by giving suitable values to x and finding the corresponding values of y from equation (15).

Torque Line.

The torque per phase (in watts) is equal to the input to the motor minus the primary copper and iron losses. Let y_n be the ordinate of O_1 referred to O′ as origin. Then

Iron loss + copper loss due to shunt-circuit current $= y_n E_1$

Primary copper-loss due to current $I = r_1 I^2$

Total loss in primary $= y_n E_1 + r_1 I^2$

Total input to primary $= (y' + y_n)E_1$

Therefore,

Torque per pnase

$$= (y' + y_n)E_1 - (y_n E_1 + r_1 I^2)$$

$$= y'E_1 - r_1 I^2$$

$$= y'E_1 - 2r_1(x_c x' + y_c y') \ \left[\text{by equation (12)}\right]$$

$$= 2r_1\left\{\left[(E_1/2r_1) - y_c\right]y' - x_c x'\right\}$$

$$= 2r_1 C_T P_T \text{ watts } \left[\text{by equation (13)}\right]$$

where $C_T = \sqrt{\{[(E_1/2r_1) - y_c]^2 + x_c^2\}}$

P_T = amperes represented by the length of the perpendicular from (x', y') to the line:—

$$[(E_1/2r_1) - y_c]y - x_c x = 0 \quad . \quad . \quad . \quad (16)$$

The torque per phase (in watts) is therefore proportional to the perpendicular from (x', y') to the line given by equation (16). This line, shown as O_1T in Fig. 22, may be called the "torque line," and can be constructed in the same way as the load line.

Power Factor.

The power factor at any current can be determined by drawing a suitable quadrant of a circle, as in the ordinary induction-motor diagram. This may be inconvenient, in which case the tangents of various phase angles should be measured on a suitable line perpendicular to $O'E_1'$ and their cosines determined from them.

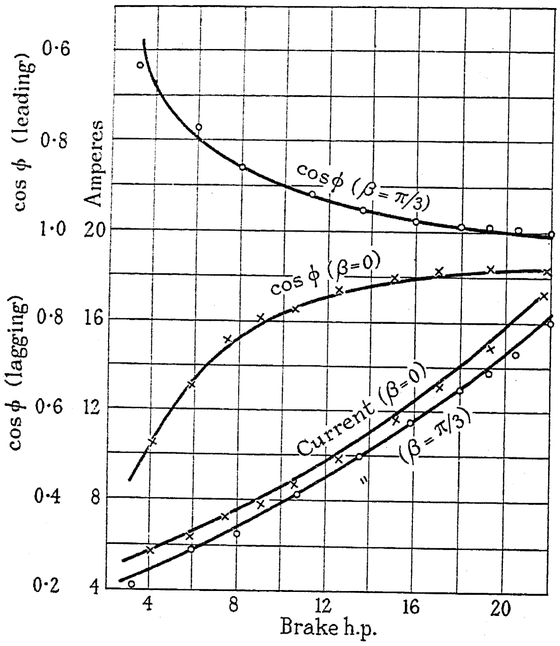


FIG. 23.—Theoretical current and power-factor curves of 17·5-h.p. "No-Lag" motor.

Current and power-factor curves of a 17·5-h.p. "No-Lag" motor for $\beta = 0$ and $\beta = \pi/3$, obtained from the circle diagrams, are shown in Fig. 23. Points on or near the curves are test points, by joining which the experimental curves were obtained.

Example.

The circle, and the copper-loss, load, and torque lines in Fig. 22 relate to a 17·5-h.p. "No-Lag" motor for $\beta = \pi/3$. They may be obtained as shown below.

$m = k \cos \beta = 0 \cdot 0335$; $n = k \sin \beta = 0 \cdot 058$; the co-ordinates of O_1, referred to O' as origin, are (x_n, y_n),

where
$$x_n = [b_0 - (n/R_2)]E_1 = -3 \cdot 6$$
$$y_n = g_0 E_1 = 0 \cdot 8$$

The co-ordinates of C, the centre of the circle, referred to O_1 as origin, are (x_c, y_c),

where
$$x_c = E_1/2X = 26$$
$$y_c = mE_1/2R_2 = 2 \cdot 6$$

The co-ordinates of the centre, referred to O′ as origin, are (22·4, 3·4).

Copper-Loss Line.

The copper-loss line is perpendicular to O_1C, and its equation is

$$x_c x - y_c y = 0$$

i.e.
$$26x - 2 \cdot 6y = 0$$

The copper loss in the secondary circuit is $R_2 I_2^2$, but, as we regard the current flowing through the secondary circuit as $(1 + m)I_2$, the resistance of the secondary circuit should be considered to be equal to $R_2/(1 + m)^2$; i.e. we should put $s = 1$ in the expression for the equivalent resistance of the secondary circuit, as we do in the case of an ordinary induction motor. Thus

$$R = r_1 + R_2/(1 + m)^2 = 1 \cdot 78 + 2 \cdot 5 = 4 \cdot 28$$

Since
$$C_R = \sqrt{(x_c^2 + y_c^2)} - 26 \cdot 2$$

and
$$2RC_R P_R = 224 P_R$$

224 is the constant by which we multiply P_R to get the copper loss per phase (in watts) in the main circuit. To get the loss in the three phases the constant by which we multiply is 3 × 224, or 672.

Load Line.

The equation of the load line O_1L is

$$[(E_1/2R) - y_c]y - x_c x = 0$$

i.e.
$$45 \cdot 9y - 26x = 0$$
$$y = 0 \cdot 565x$$

Referred to O_1 as origin, the co-ordinates of four points on this line are:—

(7·6, 4·3); (11·6, 6·6); (15·6, 8·9); and (19·6, 11·1).

If graph paper is being used it is very convenient to take O′ as origin, and the co-ordinates of the four points on the load line then are:—

(4, 5·1); (8, 7·4); (12, 9·7); and (16, 11·9).

The constant by which the amperes represented by P_L have to be multiplied to get the output per phase (in watts) is

$$2RC_L = 8 \cdot 56\sqrt{(45 \cdot 9^2 + 26^2)} = 454$$

The output for the three phases is

$$3 \times 454 P_L \text{ watts} = 1 \cdot 83 P_L \text{ h.p.}$$

The maximum output is proportional to P_L (max.), the intercept—between the circle and the load line—of the perpendicular from the centre to the load line, and is equal to 1·83 × 15·6, or 28·5 h.p.

Torque Line.

The equation of the torque line O_1T is

$$\left[(E_1/2r_1) - y_c\right]y - x_cx = 0$$

i.e.

$$114y - 26x = 0$$

$$y = 0\cdot228x$$

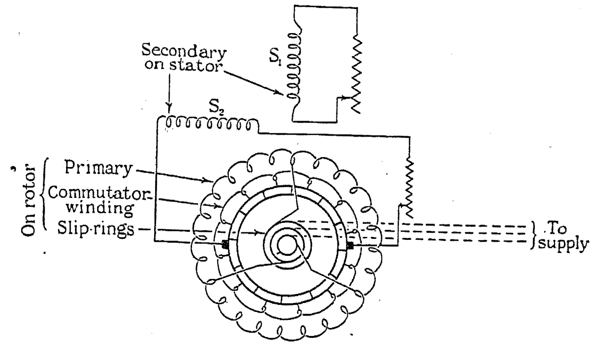


FIG. 24.—Diagram of Fynn-Weischel motor.

Referred to O_1 as origin, four points on this line are:—

(7·6, 1·7); (11·6, 2·7); (15·6, 3·6); and (19·6, 4.5).

Referred to O′ as origin, the co-ordinates of these points are:—

(4, 2·5); (8, 3·5); (12, 4·4); and (16, 5·3).

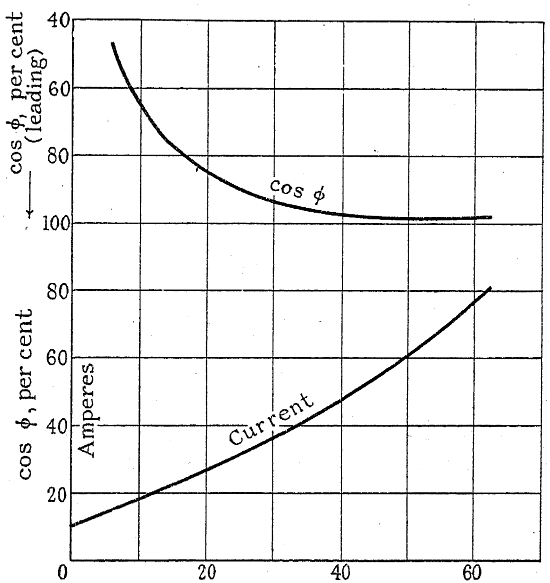


FIG. 25.—Characteristics of 50-h.p. "Tru-Watt" motor.

The constant by which the amperes represented by P_T have to be multiplied to get the torque per phase of the motor (in watts) is

$$2r_1C_T = 3\cdot56\sqrt{(114^2 + 26^2)} = 417$$

Torque for the three phases

$$= 3 \times 417P_T \text{ watts} = 1\cdot25P_T \text{ kW}$$

The maximum torque is proportional to P_T (max.), the intercept—between the circle and the torque line —of the perpendicular from the centre to the torque line, and is equal to 1·25 × 22·6, or 28·4 kW.

THE FYNN-WEISCHEL OR "TRU-WATT" MOTOR.

A number of compensated motors in which a frequency convertor is employed to excite the secondary by direct current have been devised by V. A. Fynn. One of these types, proposed in 1923, is known as the Fynn-Weischel motor.[*] A diagrammatic sketch of a 2-pole Fynn-Weischel motor, to which Messrs. Crompton Parkinson, Ltd., have given the trade name of the "Tru-Watt" motor, is shown in Fig. 24. As in the "No-Lag" motor, the primary and commutator windings are located in the same rotor slots and the secondary is on the stator, but the brushes rest 180° apart on the commutator. The secondary has two phases displaced 90° from each other. One of these is connected to the brushes through a variable resistance, and the other is short-circuited on itself through a variable resistance.

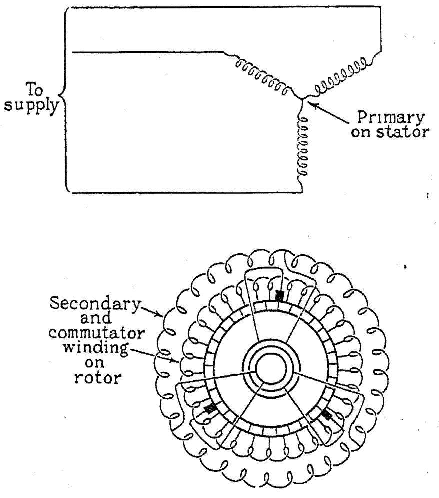


FIG. 26.—Diagram of Torda motor.

The motor is started with resistances full on in both the secondary phases, and runs up as an ordinary induction motor. When the resistances are gradually cut out, the rotor speed approaches that of synchronism, the voltage induced in phases S_1 and S_2 becoming smaller and smaller compared with the commutator voltage. When all the resistances are cut out the rotor runs up to synchronism and phase S_2 is excited by the voltage from the commutator; phase S_1 is short-circuited on itself and acts as a damper winding. The motor is thus equivalent to a synchronous induction-motor d.c. exciter set.

Fig. 25 shows the current and power-factor characteristics of a 50-h.p. Crompton Parkinson "Tru-Watt" motor with the brushes in the position of maximum compensation. The characteristics can be altered by rocking the brushes, but it is considered advisable to leave them where they are set by the manufacturers.

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[*] *Electrician*, 1923, vol. 91, p. 572.

THE TORDA OR "ALL-WATT" MOTOR.

A diagram of the Torda motor, to which the trade name of "All-Watt" has been given by the General Electric Co., is shown in Fig. 26. The primary and secondary of this motor are respectively on the stator and rotor, as in an ordinary slip-ring induction motor. The commutator winding is on the rotor and is placed in separate slots from those which carry the secondary; it is connected to the slip-rings through three brushes resting 120° apart on the commutator, supposing the commutator winding to be a 2-pole one.

Let the secondary be disconnected from the commutator brushes and short-circuited, and let a suitable 3-phase voltage be impressed on the primary. The machine will then run as an ordinary induction motor. If the primary and secondary are also wound for two poles, the main flux of the motor will induce between the commutator brushes an e.m.f. which is proportional to the slip but is of supply frequency—as in the Heyland motor—and it will be impossible to connect the commutator to the slip-rings. The ingenuity of this motor lies in the fact that the commutator winding has a different number of poles from the primary and secondary windings, with the result that no e.m.f. is induced between the brushes by the main flux, i.e. there is no mutual inductance between the primary and the commutator winding and the latter can be connected to the slip-rings. If the connections are such that secondary current of slip frequency led into the commutator creates a flux rotating in the same direction as the motor, then an e.m.f. leading the secondary current by 90° will be generated in the commutator winding—as in the Leblanc phase advancer. Thus this motor is an ingenious combination of an induction motor and a Leblanc phase advancer.

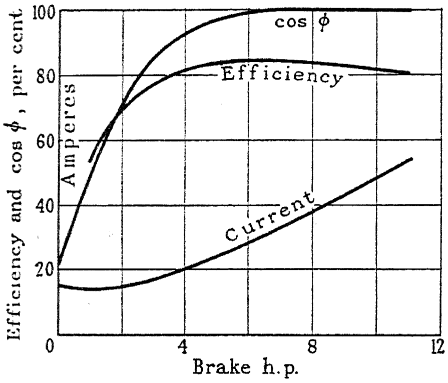

FIG. 27.—Characteristics of 12-h.p. Torda motor.

Fig. 27 shows the current, power factor, and efficiency curves of a 12-h.p. Torda motor built into the frame of a standard 9·5-h.p. induction motor.

CONCLUSION.

Whatever objections there may be to the use of these motors, commutation trouble cannot be one of them. About 6 years ago the author tested a Schrage* motor (a twin sister of the Osnos motor) and was surprised to find that it only sparked inappreciably even up to about 50 per cent overload at several brush settings. In both the 17·5-h.p. machine referred to above and a Pensabene* motor [similar to modification (*a*) of the Heyland motor] tested by the author no commutation troubles were experienced, and it is his opinion that a sound construction of the commutator and the use of suitable brushes are all that is necessary to prevent the motors referred to in this paper from sparking unduly.

The author wishes to record his thanks to Prof. Miles Walker for his help, guidance, and suggestions, to the British Thomson-Houston Co. for the loan (through Prof. Walker) of a 17·5-h.p. "No-Lag" motor and the curves of a 250-h.p. "No-Lag" motor, and to Mr. A. A. Ashour, B.Sc., for his help in carrying out the tests mentioned in the paper.

APPENDIX.

EQUATION OF THE CURRENT LOCUS OF THE OSNOS MOTOR.

Take O_1 (Fig. 17) as the origin, and O_1x and O_1y as the co-ordinate axes. Let

O_1y represent the direction of the impressed e.m.f.

(x, y) = co-ordinates of P, the extremity of I, the vector representing the current in the main circuit.

ψ = angle between I and O_1y, the direction of the impressed e.m.f., ψ being considered positive when I lags.

b = susceptance of the main circuit in Fig. 8.

g = conductance of the main circuit in Fig. 8.

Then

$$bE_1 = I \sin \psi = x \quad . \quad . \quad . \quad . \tag{17}$$

$$gE_1 = I \cos \psi = y \quad . \quad . \quad . \quad . \tag{18}$$

Total reactance of the main circuit

$$= \frac{b}{b^2 + g^2} = \frac{bE_1^2}{b^2E_1^2 + g^2E_1^2}$$

(multiplying numerator and denominator by E_1^2).

Substituting for bE_1 and gE_1 from (17) and (18),

Total reactance of the main circuit

$$= \frac{xE_1}{x^2 + y^2}$$

Total resistance of the main circuit

$$= \frac{g}{b^2 + g^2} = \frac{gE_1^2}{b^2E_1^2 + g^2E_1^2}$$

(multiplying numerator and denominator by E_1^2).

Substituting for bE_1 and gE_1 from (17) and (18),

Total resistance of the main circuit

$$= \frac{yE_1}{x^2 + y^2}$$

---

* See *Elektrotechnische Zeitschrift*, 1914, vol. 35, p. 89.

* See *Engineer*, 1925, vol. 139, p. 624.

Since the total reactance and resistance of the main circuits are respectively

$$\left[\frac{X}{1+m} - \frac{mX}{(s+m)(1+m)}\right] \text{ and } \left[r_1 + \frac{R_2}{(s+m)(1+m)}\right]$$

therefore

$$\frac{xE_1}{x^2+y^2} = \frac{X}{1+m} - \frac{mX}{(s+m)(1+m)} \quad . \quad (19)$$

$$\frac{yE_1}{x^2+y^2} = r_1 + \frac{R_2}{(s+m)(1+m)} \quad . \quad . \quad (20)$$

Transposing $X/(1+m)$ and r_1 to the left, equations (19) and (20) become equations (21) and (22) respectively.

$$\frac{x(1+m)E_1 - X(x^2+y^2)}{(1+m)(x^2+y^2)} = -\frac{mX}{(s+m)(1+m)} \quad (21)$$

$$\frac{yE_1 - r_1(x^2+y^2)}{x^2+y^2} = \frac{R_2}{(s+m)(1+m)} \quad . \quad (22)$$

Dividing (21) by (22) eliminates the slip (s) and gives

$$\frac{x(1+m)E_1 - X(x^2+y^2)}{(1+m)\left\{yE_1 - r_1(x^2+y^2)\right\}} = -\frac{mX}{R_2} \quad . \quad (23)$$

Simplifying equation (23),

$$x^2 + y^2 - 2X_c x - 2Y_c y = 0 \quad . \quad . \quad (24)$$

where X_c and Y_c are given by equations (5) and (6) on page 374.

Equation (24) represents a circle if X_c and Y_c are constant, and this is so for any particular brush setting if R_2 remains the same.

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A METHOD FOR DETERMINING THE EFFECT OF THE EARTH ON THE RADIATION FROM AERIAL SYSTEMS.*

By J. S. McPetrie, B.Sc.

[From the National Physical Laboratory.]

(*Paper first received* 25*th June, and in final form* 11*th December*, 1931.)

Summary.

In an earlier paper† the author described a graphical method for determining the magnitude and phase of the electric field in the neighbourhood of an aerial carrying a current of known distribution. The major portion of that paper neglected the effect of the earth, although an indication was given of a method for taking account of the image of the aerial in the earth. The first part of the present paper elaborates this explanation and shows how the results given in the earlier paper may be modified in order to take account of the electrical constants of the earth's surface. A formula is deduced for the field at any point near the earth's surface due to a given doublet, and it is shown how this formula may be extended in order to determine the field at various distances from an aerial carrying a current of known distribution. The second part of the paper shows how the field at any distant point may be found directly for any number of equal aerials and reflectors from a knowledge of the field at the same point due to one aerial and reflector alone. The current in the reflector wire need not be equal in magnitude or in phase to that in the aerial, and the components of the array may be either vertical or horizontal.

(1) Reflection of Plane Waves at the Earth's Surface.

The well-known formulæ for the reflection of plane electromagnetic waves at a conducting surface have been put in a very convenient form by Wilmotte.‡ He shows that they may be interpreted so that an element of current-length $I\delta l$ (Fig. 1) has for image a similar element-length but of strength $(K-jK')I\delta l$ at a distance below the conducting surface equal to that of the doublet $I\delta l$ above it. K and K' are functions of the angle between the direction of transmission and the vertical, and their values depend on whether the element coincides with, or is perpendicular to, the normal to the earth's surface through the centre of the doublet. When the element of current-length lies in the plane of propagation, K and K' are represented by K_i and K_i' whose values are determined by the relation

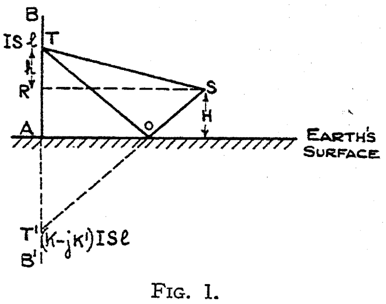

Fig. 1.

$$K_i-jK_i' = \frac{(\kappa^2+4\sigma^2/f^2)\cos^2\theta-(c^2+d^2)-2j\cos\theta(\kappa d+2c\sigma/f)}{(\kappa^2+4\sigma^2/f^2)\cos^2\theta+(c^2+d^2)+2\cos\theta(\kappa c-2d\sigma/f)} \quad (1)$$

While if it is perpendicular to the plane of propagation, K and K' become K_P and K_P' where

$$K_P - jK_P' = \frac{\cos^2\theta-(c^2+d^2)-2jd\cos\theta}{\cos^2\theta+(c^2+d^2)+2c\cos\theta} \quad . \quad (2)$$

In relations (1) and (2), j is equal to $\sqrt{-1}$, σ is the conductivity of the ground in electrostatic units, κ is the dielectric constant of the earth, f is the frequency of the wave incident at the angle θ to the earth's surface, and the values of c and d are given by

$$c^2-d^2=\kappa-\sin^2\theta;\ cd=-\sigma/f$$

Curves in which the values of K_i, K_i', K_P, and K_P', are plotted against the angle of incidence θ are given in Wilmotte's paper for different values of κ and σ/f.

If the doublet $I\delta l$ (Fig. 1) is at a sufficient distance from the point O on the earth's surface for the incident wave to be sensibly plane at O, relations (1) and (2) give the true reflection coefficients. The reflected wave at S is due to the currents set up in the earth by the incident wave. Relations (1) and (2) must therefore not be applied to cases in which the field is required on long wavelengths at points close to the earth's surface. In antenna arrays the aerials are usually raised above the earth's surface, so that in such cases the reflection coefficient is given very approximately by (1) and (2). Verman,† in some experiments on the configuration of the field at various heights above the earth's surface, found that discrepancies between the above theory and experiment only became apparent when the height was less than one-tenth of the wavelength. These discrepancies he attributed to experimental error, but they were more probably due to the proximity of the ground.

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* The Papers Committee invite written communications, for consideration with a view to publication, on papers published in the *Journal* without being read at a meeting. Communications (except those from abroad) should reach the Secretary of the Institution not later than one month after publication of the paper to which they relate.

† See Reference (1) on page 390.

‡ See Reference (2).

† See Reference (3).

(2) ATTENUATION OF FIELD STRENGTH FROM A GIVEN DOUBLET FOR POINTS NEAR THE GROUND.

Consider the element $I\delta l$ (Fig. 1) with its image $(K - jK')I\delta l$. $I\delta l$ may lie in either the vertical or the horizontal plane. Suppose the total field due to $I\delta l$ is required at the point S whose distance from the earth's surface is sufficient to satisfy the conditions outlined in the previous paragraph. Let the optical path-difference between the two paths TOS and TS be represented by the phase angle α. If the field at S due to $I\delta l$ alone be E, the field at S due to its image is $(K - jK')E$ and lags in phase on E by the angle α. S is supposed to be near the earth's surface, so that the angle between the directions of these two fields is small. The total field at S due to the two fields can be shown to be equal to

$$E\sqrt{(1 + K^2 + K'^2 + 2K\cos\alpha - 2K'\sin\alpha)} \quad . \quad (3)$$

The numerical value of this expression can be obtained from equation (1) or equation (2) according as $I\delta l$ lies in the vertical or the horizontal plane.

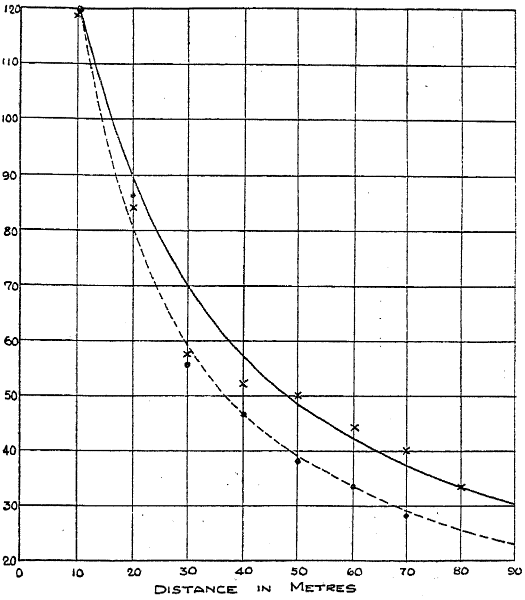

FIG. 2.—Comparison between theoretical curves and experimental results obtained at National Physical Laboratory on a wavelength of 5·5 metres.

Calculated curves { ——— $\kappa = 10$, $\sigma/f = 40$.
-------- $\kappa = 10$, $\sigma/f = 10$.

Experimental results { ● July 1930.
× August 1930.

The field from a vertical doublet at any point lies in the vertical plane; when the doublet is horizontal, however, the field is only truly horizontal in the plane through the centre of the doublet and perpendicular to its axis. In any other direction the doublet has a component in the plane of propagation which gives rise to a field with a vertical component. In order to obtain a complete solution for the field from a horizontal doublet we must therefore resolve the field into its components in and perpendicular to the plane of propagation. This point will be considered further in connection with the study of antenna arrays in a later section of this paper. A consideration of equation (3) shows that the horizontal field from a horizontal doublet is very small near the earth's surface. The small vertical component, however, is not so rapidly attenuated, so that the field from a horizontal aerial is usually found to lie in the vertical plane when measured near the earth's surface.

In Fig. 2 a comparison is made between some experimental results on the field strength from a small vertical loop transmitter working on a wavelength of 5·5 metres and theoretical curves calculated from (1) and (3). The transmitter and receiver were at heights of about 4 and 3 ft. respectively above the ground. It will be seen that when κ is assumed to be 10 and σ/f lies between 10 and 40, satisfactory agreement is obtained between theory and experiment. The conductivity value so obtained is in good agreement with those given by different methods. A more sensitive way of determining the conductivity would be to vary the heights of the transmitter and receiver, keeping the distance between them constant.

(3) ATTENUATION NEAR THE GROUND OF THE FIELD STRENGTH FROM AN AERIAL CARRYING ANY CURRENT DISTRIBUTION.

The field at any point near the ground due to a given aerial may be obtained by integrating the fields at the point due to the various doublets in the aerial. The integration is most conveniently made by the graphical method described in a previous paper.* Let AB (Fig 1) represent a vertical aerial carrying any given distribution of current, and suppose the field due to AB is required at the point S. Draw SR parallel to the earth's surface so as to cut the aerial AB at the point R. The field at S due to unit doublet at any such point in AB as T is obtainable from the previous paper* when the horizontal distance RS and the vertical distance TR are known. With the given current distribution along AB the doublet at T may not be of unit strength; if it is not, the field at S due to the doublet at T is obtained by multiplying the field at S due to unit doublet at T by the strength of the doublet actually at T. In the paper referred to above, the field at S was resolved into its two components in phase and in quadrature leading the current at A. By this means the integration of the field at S due to the various doublets in AB was simplified and the phase of the total field at S could also be determined.

Each doublet such as that at T has an image at T′ of strength $(K_i - jK_i')$ times the strength of the doublet at T. The values of K_i and K_i' depend on the angle RTO, which is equal to the angle RT′S. For each point T in AB, therefore, there is an image-point T′ in AB′ such that AT′ is equal to AT. If S is at height H above the earth, RT is equal to h, and SR is equal to D, then

$$\mathrm{T'R} = h + 2H$$

and $$\tan\underline{/\mathrm{ST'R}} = \tan\underline{/\mathrm{ATO}} = D/(h + 2H)$$

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* See Reference (1).

From the value of the angle ATO deduced from this relation we can determine the values of K_i and K_i'. It will be noticed, therefore, that the strength of the image of T depends on the position of T in AB, as well as on the current at T.

The vertical field at S due to a doublet at T′ a distance $(h + 2H)$ below R, is exactly the same as the vertical field at S due to an equal doublet at the point $(h + 2H)$ above R. The vertical field at S due to unit doublet at T′ is therefore obtainable from the earlier paper* when the height of the doublet in the aerial is $(h + 2H)$. Let P and Q represent the in-phase and in-quadrature components of the field at S referred to the current at R, due to a doublet of strength equal to that at T but at a height $(h + 2H)$ above the point at which the field is considered. The actual component fields at S due to an element $(K_i - jK_i')$ times the strength of the doublet at T will have in-phase and in-quadrature component fields equal to $(K_iP + K_i'Q)$ and $(K_iQ - K_i'P)$ respectively (see Fig. 3). We can thus determine the vertical field at S due to any doublet such as that at T in AB, and its image in the ground.

If these components of the vertical field at S are determined for a few discrete doublets in AB and their images in AB′, the following method may be used to determine the total field at S due to the complete aerial AB and its image in the ground. With abscissæ representing the length BAB′, erect as ordinates at the corresponding values of BT and BT′ the magnitudes of the components of the fields at S, in phase and in quadrature with the current at R, due to the doublet at T and its image at T′. If this procedure is carried out for a few discrete positions of the doublet T in AB, two curves are obtained the ordinates of which represent the components of the field at S due to different doublets in AB. The areas which these two curves make with the axis of abscissæ are proportional respectively to the total vertical fields at S in phase and in quadrature with the current at R. The constant of proportion can be determined in any particular case. As the two rectangular components are determined separately, the field at S due to AB and its image is determined both in magnitude and in phase.

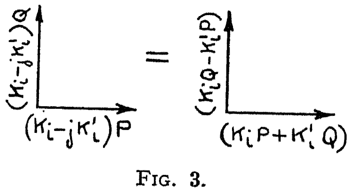

FIG. 3.

At the Radio Research Station of the Department of Scientific and Industrial Research an experimental study of field strength in the neighbourhood of a small vertical aerial was made by Barfield and Munro. A theoretical curve deduced by the method detailed above shows how closely the theory may be made to follow their experimental results. They set up, in the field of a small transmitter, an aerial whose natural frequency could be varied. For various degrees of detuning of this aerial from the frequency of the transmitter, they measured the field strength at a distance of 1 wavelength from the small aerial on the side remote from the transmitter. Curve A (Fig. 4) gives the ratio of the field strength measured with this "shadow aerial" in position and tuned to various adjacent wavelengths, to that measured when it was absent. The shadow aerial was almost one-quarter of a wavelength in height, and the field re-radiated from such an aerial and its image was determined by the method described above. The phase of this field with respect to the field incident from the transmitter for different conditions of tuning of the shadow aerial was determined from an experimental resonance curve obtained by Barfield and Munro. The amplitude of the re-radiated field was obtained by making the theoretical curve coincide at one point with the experimental curve. The data given by this superposition were sufficient to determine the complete theoretical curve. Theoretical curves have been drawn for different possible values of dielectric constant and conductivity of the earth's surface. The theoretical curve obtained by the same method when the effect of the earth is neglected is also shown in Fig. 4. The percentage change in field strength is small, so that the experiment does not lend itself to an accurate determination of the electrical constants of the earth's surface. It is to be noted, however, that the effect of the earth may be appreciable and must be taken into account in problems on the field strength in the neighbourhood of the aerial. The reaction of the receiver on the shadow aerial has been neglected. This may also be of some importance and would act somewhat similarly to the image of the aerial in the earth.

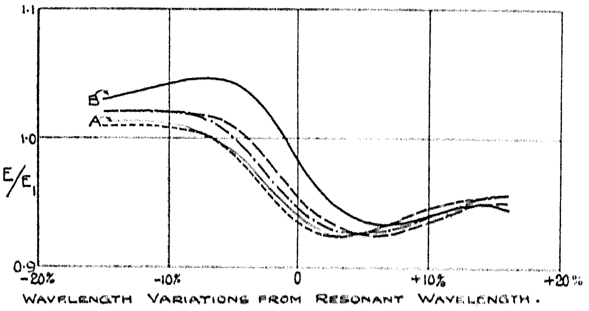

FIG. 4.

Curve A. Experimental.
Curve B. Theoretical, neglecting image in earth.
— — — $\kappa = 10$ or 5; $\sigma/f = 10$ or 5.
- — - — $\kappa = 2$; $\sigma/f = 5$.
- - - - - $\kappa = 0$; $\sigma/f = 5$.

The distance from the aerial at which the field is studied must not be less than about $\lambda/4$, as if smaller distances than this were employed the waves from the various doublets would not be sufficiently nearly plane at their point of reflection at the earth for the values of the reflection coefficients given by relations (1) and (2) to be approximately accurate.

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* *Loc. cit.*

(4) VERTICAL POLAR RADIATION DISTRIBUTION OF AERIAL CARRYING ANY CURRENT DISTRIBUTION.

(*a*) *Vertical Aerial Alone, Neglecting the Effect of the Image in the Earth.*

Let AB (Fig. 5) represent the aerial, and suppose the field due to it is required at a great distance r in the direction making an angle θ with the vertical. Assume the lower end of AB to lie on the earth's surface. This is the most general case, as if in any particular instance the aerial extends only from, say, B to P, the field in the direction θ is obtained from that due to AB by assuming the current to be zero over the part AP. Let the current at P, any point in AB, be I amperes, and suppose it has the same phase as the current at B. The field due to the doublet $I\delta h$ at P in the direction θ leads that due to the doublet at A by the angle $(2\pi/\lambda)h \cos \theta$, where h is the height of P in AB and λ is the wavelength of the current in AB. The intensity of the field in the direction E_θ due to the doublet $I\delta h$ at P is

$$\frac{60\pi I \sin \theta \delta h}{\lambda r} \text{ volts per metre.}$$

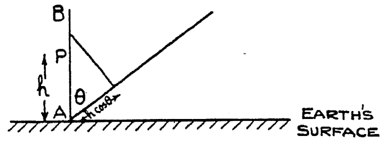

FIG. 5.

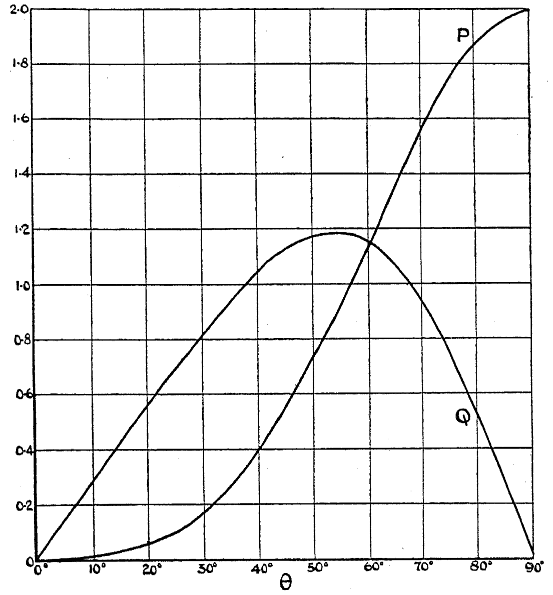

FIG. 6.

Curve P.—Total electric field in phase with field due to doublet at base of ½λ aerial.
Curve Q.—Total electric field in quadrature (leading) with field due to doublet at base of ½λ aerial.

As the point in the direction θ at which the field is considered is at a great distance from AB, θ and r may be assumed to be constant over the whole aerial AB when determining the amplitude of the field, but the difference in r must be taken into account when determining the relative phases of the elementary fields in the direction θ due to the various doublets in AB. In order to simplify the integration of these elementary fields, they will be resolved into their components in phase and in quadrature (leading) with the field in the direction θ due to the doublet at A. The elementary field in the direction θ due to the doublet at P leads that due to the doublet at A by the angle $(2\pi h/\lambda) \cos \theta$, so that for the point P these in-phase and in-quadrature component fields are respectively

$$\frac{60\pi I \sin \theta \delta h}{\lambda r} \cos \left(\frac{2\pi h}{\lambda} \cos \theta\right) = P$$

and

$$\frac{60\pi I \sin \theta \delta h}{\lambda r} \sin \left(\frac{2\pi h}{\lambda} \cos \theta\right) = Q$$

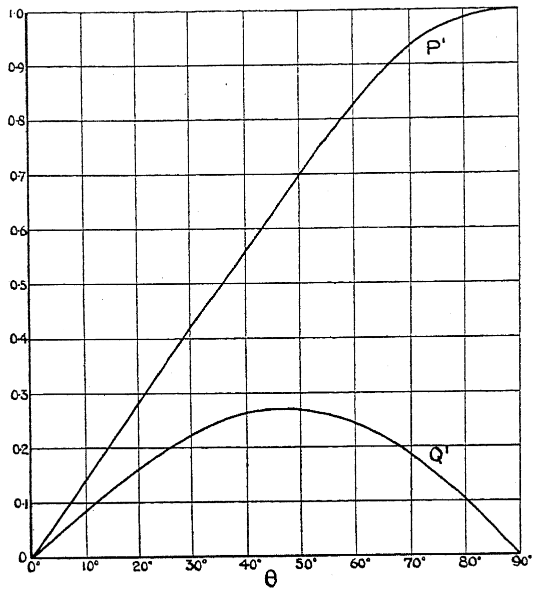

FIG. 7.

Curve P′.—Total electric field in phase with field due to doublet at base of ¼λ aerial.
Curve Q′.—Total electric field in quadrature (leading) with field due to doublet at base of ¼λ aerial.

Curves of $\cos \left(\frac{2\pi h}{\lambda} \cos \theta\right)$ and $\sin \left(\frac{2\pi h}{\lambda} \sin \theta\right)$ for different values of h/λ and θ will be found in Wilmotte's paper.* Suppose two curves are drawn in which the values of these in-phase and in-quadrature fields are plotted as ordinates against the corresponding values of h/λ as abscissæ. The total fields at the distant point in the direction E_θ, in phase and in quadrature respectively with the elementary field due to the doublet at A, are proportional to the respective areas which these two curves make with the axis of h/λ. From the areas thus obtained we can determine therefore both the magnitude and the phase of the field in the direction θ due to the complete aerial AB. As before, the computation is purely graphical, so that the current distribution along AB need not conform to any simple mathematical function.

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* See Reference (2).

Figs. 6 and 7 give the polar radiation distributions for a half-wave and a quarter-wave aerial respectively. The curves give the components of the total electric field E_θ in any direction making an angle θ with the axis of the aerial, in phase and in quadrature with the field due to the doublet at the base of the aerial. The angle by which the phase of the total field in the direction θ leads that at the same point due to the doublet at the lower end A of the aerial, is given by the inverse tangent of the ratio of the in-quadrature and in-phase components of the field in that direction. One quadrant only is given, as obviously the other quadrant would have a similar radiation distribution.

(b) *Vertical Aerial and its Image.*

Each doublet $I\delta h$ in AB (Fig. 1) has an image doublet of strength $(K_i - jK_i')I\delta h$, the field from which in the direction θ lags on that from the doublet at A by an angle equal to that by which the field from $I\delta h$ leads that field in the same direction. Thus if OA (Fig. 8) represents the phase of the field in the direction θ to the vertical due to a doublet at A, and OB represents vectorially the field due to any doublet in AB, the field due to the image of that doublet is represented by $(K_i - jK_i')$ times an equal vector lagging on OA by an angle equal to that by which OB leads OA. The point at which the field is required is at such a distance from AB that the direction θ is the same for all points in the aerial. The components K_i and K_i' of the reflection coefficient are therefore the same for all points in AB. Hence, if the resultant field due to the complete aerial AB in the direction θ leads that due to the doublet at A by the angle α, the resultant field due to the image of AB will be $(K_i - jK_i')$ times as large and will lag on OA by the same angle α. The magnitude and phase of the field due to AB have already been determined in Section 4(*a*). The result can readily be modified to take account of the image of AB in the earth.

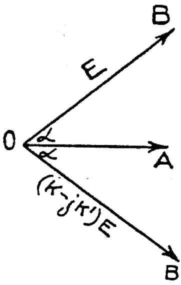

FIG. 8.

The resultant field in the direction θ can be shown to be equal to

$$E\sqrt{(1 + K_i^2 + K_i'^2 + 2K_i \cos 2\alpha - 2K_i' \sin 2\alpha)} \quad (4)$$

in which E is the total field due to AB, and α is the angle by which the phase of E leads the elementary field due to the doublet at A. The phase of the resultant field leads this zero-phase field by the angle

$$\text{arc tan} \frac{(1 - K_i) \sin \alpha - K_i' \cos \alpha}{(1 + K_i) \cos \alpha - K_i' \sin \alpha} \quad . \quad . \quad (5)$$

The above method, in which the total field is determined by a modification of the field due to the aerial alone, has the advantage that a series of values of the electrical constants of the earth can be introduced without involving a complete recalculation.

(c) *Horizontal Aerial.*

If the aerial is horizontal and we wish to find the horizontal field at a distant point in the direction making angles θ with the vertical and β with the axis of the aerial, we may proceed in the following way. The field due to the aerial alone in the direction making angle β with its axis is the same as the vertical field from a similar vertical aerial in the direction making angle β with the vertical. This field is obtained directly from Section 4(*a*) by changing θ to β. Suppose the aerial is at a height h above the ground; each doublet in it has a horizontal image $(K_P - jK_P')$ times its strength and distant $2h$ below it. The difference in the distances of the point at which the field is required from any doublet in AB and from the image doublet of the latter is obviously $2h \cos \theta$, which represents a phase difference of $(4\pi h/\lambda) \cos \theta$. If E is the horizontal field in the direction (θ, β) due to the aerial alone, the field due to the image is $(K_P - jK_P')E$ and lags on the field due to the aerial by the angle $(4\pi h/\lambda) \cos \theta$. K_P and K_P' are the components of the reflection coefficient for a horizontally-polarized wave for the angle of incidence θ. The total horizontal electric field due to the aerial and its image is therefore

$$E\sqrt{\left[1 + K_P^2 + K_P'^2 + 2K_P \cos\left(\frac{4\pi h}{\lambda} \cos \theta\right) - 2K_P' \sin\left(\frac{4\pi h}{\lambda} \cos \theta\right)\right]} \quad . \quad (6)$$

Thus we can obtain, directly, the horizontal field due to a horizontal aerial and its image in the earth from a knowledge of the horizontal field due to the aerial alone. It is to be noted, also, that the field due to a horizontal aerial is obtainable directly from that due to a vertical one, so that the curves given in Figs. 6 and 7 apply to both vertical and horizontal aerials.

A little consideration will show that a horizontal aerial gives rise to a vertical electric force, as the total electric vector is perpendicular to the radius vector in any direction. The vertical electric force due to the above aerial in the directions making angles θ with the vertical and β with the axis of the aerial, is $E \cos \theta \cot \beta$, so that the total vertical electric field in this direction due to the aerial and its horizontal image is

$$E \cos \theta \cot \beta\sqrt{\left[1+K_P^2+K_P'^2+2K_P \cos\left(\frac{4\pi h}{\lambda} \cos \theta\right) -2K_P' \sin\left(\frac{4\pi h}{\lambda} \cos \theta\right)\right]} \quad . \quad (7)$$

(5) ANTENNA SYSTEM.

In certain aerial systems each conductor consists of a number of similar elements placed vertically above one another and carrying the same current. (The elements may be either vertical or horizontal.) Suppose there are m such elements so disposed that the vertical distance between consecutive similar points is h (Fig. 9). The resultant field due to the m elements can be obtained directly from that due to one. The phase difference in the direction θ of the fields from consecutive similar elements is $(2\pi h/\lambda)\cos\theta$. If E be the field due to the lowest element, the resultant e.m.f.'s in phase and in quadrature (leading) with it due to the m elements are

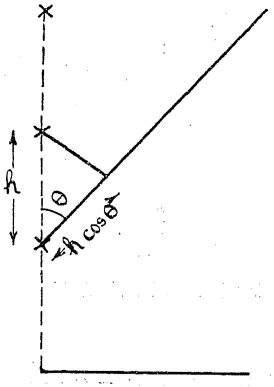

FIG. 9.

$$E\left\{1+\cos\left(\frac{2\pi h}{\lambda}\cos\theta\right)+\cos\left(\frac{4\pi h}{\lambda}\cos\theta\right)\right.$$
$$\left.+\ldots\cos\left[\frac{2\pi(m-1)h}{\lambda}\cos\theta\right]\right\}$$

and

$$E\left\{\sin\frac{2\pi h}{\lambda}\cos\theta+\sin\left(\frac{4\pi h}{\lambda}\cos\theta\right)\right.$$
$$\left.+\ldots\sin\left[\frac{2\pi(m-1)h}{\lambda}\cos\theta\right]\right\}$$

respectively.

It can be shown from these relations that the total field in the direction making an angle θ with the vertical, due to the m elements, is

$$\frac{\sin\left[(m\pi h/\lambda)\cos\theta\right]}{(\pi h/\lambda)\cos\theta}E \quad . \quad . \quad . \quad . \quad . \quad (8)$$

and leads in phase that due to the lowest element by the angle

$$\frac{(m-1)\pi h}{\lambda}\cos\theta \quad . \quad . \quad . \quad . \quad . \quad (9)$$

The angle by which the resultant field due to the m elements leads in phase that due to the doublet at the earth's surface is therefore

$$\alpha+\frac{(m-1)\pi h}{\lambda}\cos\theta$$

The total field in a direction making an angle θ with the vertical, due to the m elements and their respective images, can be shown—by exactly the same reasoning as that given above—to be equal to

$$E\frac{\sin\left[(m\pi h/\lambda)\cos\theta\right]}{\sin(\pi h/\lambda)\cos\theta}$$
$$\sqrt{(1+K^2+K'^2+2K\cos 2\beta-2K'\sin 2\beta)} \quad . \quad (10)$$

where E is the field in the direction θ due to the lowest element alone, and the angle β is equal to

$$\alpha+\frac{(m-1)\pi h}{\lambda}\cos\theta$$

K and K' are written K_i and K_i', or K_P and K_P', according as the elements are vertical or horizontal.

Thus, having determined the polar diagram of a given aerial without considering its image in the earth, we can determine the true radiation distribution taking into account the image in the earth; we can also determine the radiation distribution of any number of such aerials placed vertically above one another with any relative displacement. The analysis perhaps appears rather tedious, but by using the curves for K, K', $\cos\left[(2\pi h/\lambda)\cos\theta\right]$, and $\sin\left[(2\pi h/\lambda)\cos\theta\right]$, the solution of any particular problem may be obtained in a relatively short time, considering the complexity of the aerial system.

(6) RADIATION DISTRIBUTION OF AN AERIAL AND EQUAL REFLECTOR.

Consider two parallel aerials A and B (Fig. 10) carrying the same current, and let the distance between them be D. It is required to find the vertical radiation distribution of the two aerials in a plane making an angle β with the plane of the aerials. The current in each aerial is known, so that the field due to either in the direction θ can be found by the method outlined in Section 4. Let $I\delta l$ be an element of current-length in A. There is a similar element of current-length in B; and suppose the phase of the current throughout B leads that in A by the angle ϕ. At distant points in the direction θ, the phase angle β between the fields due to the two elements is

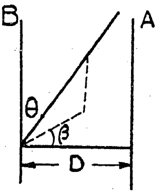

FIG. 10.

$$\frac{2\pi D}{\lambda}\sin\theta\cos\beta-\phi$$

The phase difference of the fields in this direction due to all similar elements in A and B is the same, so that the phase difference between the fields due to the complete aerials A and B will also be equal to

$$\frac{2\pi D}{\lambda}\sin\theta\cos\beta-\phi$$

The current distributions in A and B are supposed to be equal, so that if E is the resultant field in the direction (θ, β) due to either aerial alone (found by the method described above) the resultant field due to the two aerials in the same direction will be equal to

$$2E \cos\left(\frac{\pi D}{\lambda} \sin\theta \cos\beta - \tfrac{1}{2}\phi\right)$$

The aerials A and B may, of course, lie in either the vertical or the horizontal plane. If they lie in the horizontal plane there is a component of the electric field strength in the vertical plane which is related in magnitude to that in the horizontal plane, as shown in Section 4(c).

(7) Radiation Distribution in a Vertical Plane of n Aerials and n Equal Reflectors.

Let the array (Fig. 11) be in two straight lines, the distance between successive aerials being d and the distance between the line of aerials and the line of reflectors D. The current in all the aerials and reflectors is assumed to be the same; but suppose that the phase of the current in the reflector wires leads that in the aerials by the angle ϕ. The field due to each aerial and its reflector, in the direction θ to the vertical and β to the plane of the aerial and reflector, is

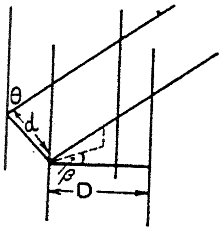

Fig. 11.

$$2E \cos\left(\frac{\pi D}{\lambda} \sin\theta \cos\beta - \tfrac{1}{2}\phi\right)$$

where E is the field in this direction due to either aerial alone. The phase difference between the fields due to each successive aerial and reflector system is $(2\pi d/\lambda) \sin\theta \sin\beta$. The total field due to the n aerials and reflectors is therefore

$$2E \cos\left(\frac{\pi D}{\lambda} \sin\theta \cos\beta - \tfrac{1}{2}\phi\right) \frac{\sin\left[(n\pi d/\lambda) \sin\theta \sin\beta\right]}{\sin\left[(\pi d/\lambda) \sin\theta \sin\beta\right]} \quad . \quad (11)$$

Thus, from the field due to a single element of aerial, we can deduce by stages the field due to any number of such elements placed vertically above one another with any relative displacement. To this field we can add the effect of the earth and then find the field at any point due to any two such equal aerials with any space and phase displacement, and lastly, from this result, we can find very simply the radiation distribution of any system of equal aerials.

(8) Radiation Distribution in a Vertical Plane when Currents in Aerials and Reflectors are not Equal.

If the currents in the reflector wires are not equal to those in the aerials, we can proceed in the following way, assuming that all the aerials and all the reflectors carry the same current. This condition is closely approximated to in some modern beam antenna systems. Consider any aerial A and its reflector B at a distance D from it. The current in A is known, so that the field in the direction (θ, β) can be determined in the usual way. Suppose the phase of this field in this direction leads by the angle α that due to the doublet at the base of the aerial A. The field due to the reflector B can also be determined; suppose its field leads by γ the phase of the field from an equi-phase doublet at the base of B. Let the intensities of the fields due to the aerial and its reflector be E and R respectively. The phase difference between E and R in the direction required is

$$\left(\alpha - \gamma - \frac{2\pi D}{\lambda} \sin\theta \cos\beta\right)$$

so that the resultant field in that direction due to A and B is equal to

$$\sqrt{\left[E^2 + R^2 + 2ER \cos\left(\alpha - \gamma - \frac{2\pi D}{\lambda} \sin\theta \cos\beta\right)\right]}$$

If there are n aerials and reflector elements distant d apart in the direction normal to D, the total field in the direction (θ, β) due to the complete array is

$$\frac{\sin\left[(n\pi d/\lambda) \sin\theta \sin\beta\right]}{\sin\left[(\pi d/\lambda) \sin\theta \sin\beta\right]} \sqrt{\left[E^2+R^2+2ER \cos\left(\alpha-\gamma-\frac{2\pi D}{\lambda} \sin\theta \cos\beta\right)\right]} \quad (12)$$

Thus the field of an antenna array in any direction may be found by obtaining the field in that direction due to any aerial element and its reflector in the way shown above, and modifying the result according to the number and relative spacing of the aerial reflector elements.

(9) Illustration of the Application of the Method to a Particular Problem.

As an example of the method of procedure in any particular problem, suppose it is required to find the radiation distribution in the vertical plane normal to the plane of a combination of twelve half-wave aerials arranged in different ways. Suppose all the aerials carry the same current and are arranged so that six act as a reflecting screen for the other six. The electrical constants of the ground (κ and σ/f) are each given the value 10, these being the probable figures for a wave-length of about 25 metres.

The magnitude of the field in any direction θ from a half-wave aerial can be determined directly from Fig. 6. It is equal to $\sqrt{(P^2 + Q^2)}$, and the angle by which the phase of the field in the direction θ leads that due to the doublet at the base of the aerial is arc tan Q/P. Suppose the base of the lowest aerial in the array is at a height $\lambda/4$ above the surface of the earth. The angle by which the phase of the field from this aerial leads the field from an equi-phase element of current at the point on the ground directly below the aerial is

$$\text{arc tan}\, Q/P + (\pi/2)\cos\theta.$$

The field due to the image of this aerial in the earth's surface is $(K - jK')\sqrt{(P^2 + Q^2)}$, and, as shown in Section 4(b), the resultant field due to the aerial and image is given by equation (4) when $\sqrt{(P^2 + Q^2)}$ is substituted for E and (arc tan $Q/P + \frac{1}{2}\pi\cos\theta$) for α. When the resultant equation is evaluated for different values of θ we obtain Fig. 12(a), which represents the radiation distribution in the vertical plane normal to that containing six half-wave aerials arranged as shown on the right of the diagram. The aerials carry a sinusoidal current distribution and their lower ends are assumed to be at a distance of $\lambda/4$ above the earth; the constants κ and σ/f are given the value 10, as indicated above.

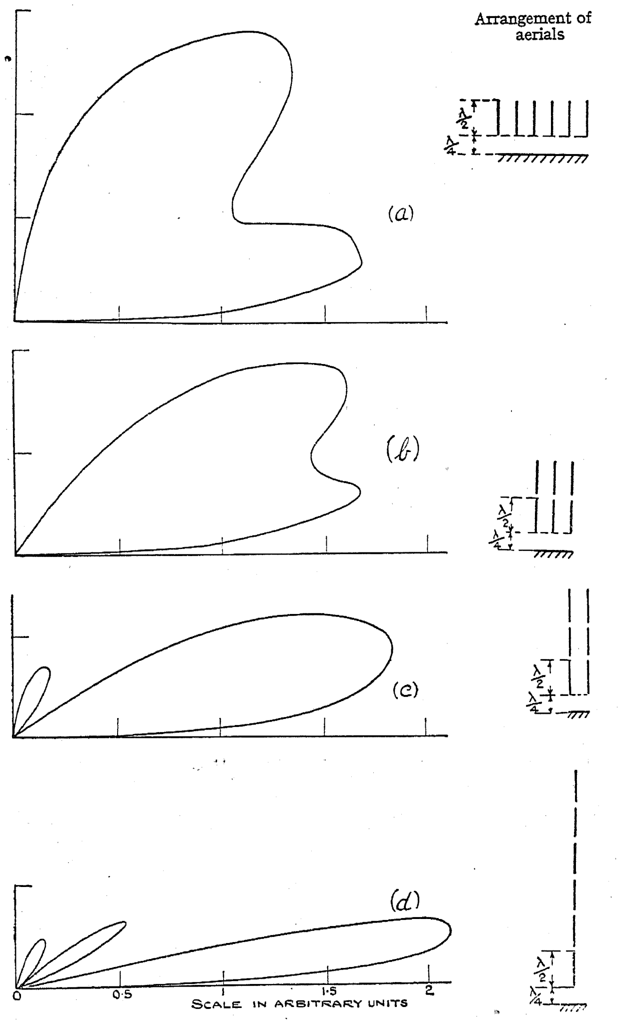

FIG. 12.—Polar radiation distribution in the vertical plane normal to that of an array consisting of a system of six half-wave aerials disposed as shown inset in each diagram.

Suppose we have a reflector B at a distance $\lambda/4$ from A (Fig. 10), the current in B being equal to that in A but leading it in phase by the angle $\pi/2$. To each doublet in A there is a corresponding equal doublet in B, and the current in the doublet in B leads in phase that in the doublet in A by the angle $\pi/2$, so that the field in the direction θ due to the doublet in B differs in phase from that due to the corresponding doublet in A by the angle $(\pi/2)(1 - \sin\theta)$. The fields due to the images of A and B differ in phase by the same angle $(\pi/2)(1 - \sin\theta)$, so that the total field in the direction θ due to the two half-wave aerials A and B and their images in the earth is equal to $2\cos\left[(\pi/4)(1 - \sin\theta)\right]$ times the field due to either aerial and its image, that is

$$(K - jK')\sqrt{(P^2 + Q^2)} \times 2\cos\left[(\pi/4)(1 - \sin\theta)\right]$$

This expression gives the radiation distribution in the vertical plane containing the two aerials (assuming again that κ and σ/f are each equal to 10). In the case of the array of six aerials considered above, with the addition of a screen of six similar reflectors at a distance of $\lambda/4$, under the same conditions, the radiation distri-

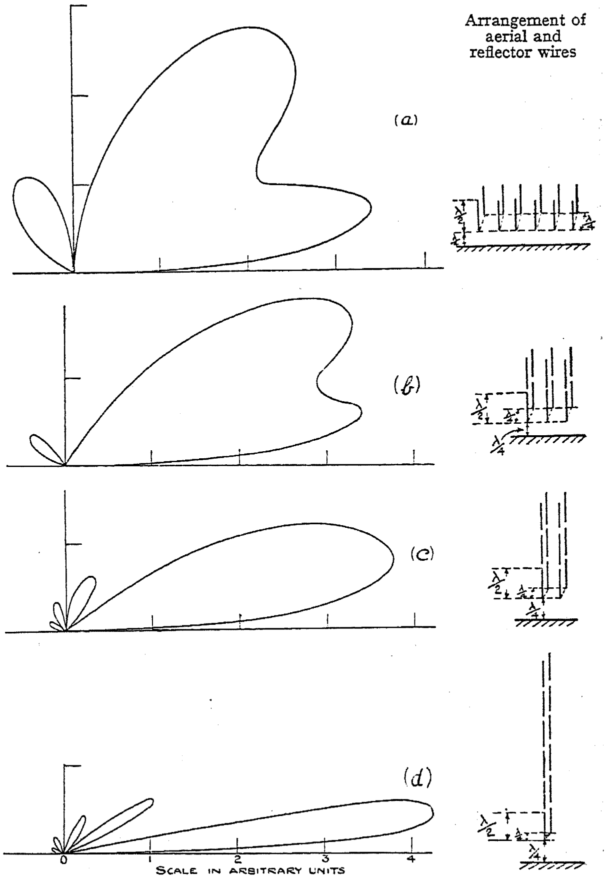

FIG. 13.—Polar radiation distribution in the vertical plane normal to that of an array consisting of a system of six half-wave aerials and six equal reflectors disposed as shown inset in each diagram.

bution in the plain normal to the array is given by the same expression, which is represented graphically in Fig. 13(*a*).

By means of equation (10) we can determine the radiation distribution from any number of half-wave aerials arranged vertically above one another. Suppose we wish to find the field from a vertical aerial consisting of a number of half-wave elements, the base of the aerial being at a height $\lambda/4$ above the ground. In this case E in equation (10) is equal to $\sqrt{(P^2 + Q^2)}$ as given by Fig. 6 for the appropriate angle θ, and the angle β is

$$\arc\tan (Q/P) + \tfrac{1}{2}m \cos \theta$$

where m is the number of half-wave elements in the aerial. For an array of six half-wave aerials we obtain the polar radiation distributions given in Fig. 12 [(*b*), (*c*), and (*d*)], for the cases in which the aerials are arranged as shown on the right of these diagrams (i.e. $m = 2$, 3, and 6 respectively).

When we consider an aerial with a reflector placed at a distance of $\lambda/4$ and carrying a current equal to that in the aerial but leading it in phase by $\pi/2$, we have to multiply the field due to the aerial alone by $2 \cos \frac{1}{4}\pi (1 - \sin \theta)$ (see Section 6). The resultant polar radiation distributions for the above three aerial arrays, with the addition of equal reflecting arrays, are shown in Fig. 13 [(*b*), (*c*), and (*d*)]. The diagrams given here show clearly the relative advantages of spreading an antenna array, with or without a reflector system, in the horizontal and vertical directions.

We have determined the radiation distribution in the plane normal to that containing the array. By means of equation (11) we can determine directly from these results the radiation distribution in any other plane from an array of such elements. The examples worked out above are admittedly particular cases, because the current was assumed to be the same in all the aerial and reflector elements. It is, however, a simple matter to make similar calculations for any practical case in which the current distribution is specified. By proceeding in the manner outlined above, therefore, the complete distribution of radiation in both vertical and horizontal planes can be determined for any given antenna system.

The work described in this paper was carried out as part of the programme of the Radio Research Board, and the author is indebted to the Department of Scientific and Industrial Research for permission to publish it. He desires also to acknowledge his indebtedness to Dr. R. L. Smith-Rose for valuable advice on the method of presentation of the paper, and to Mr. B. J. Byrne for assistance in the computing work involved.

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(2) R. M. Wilmotte: "General Formulæ for the Radiation Distribution of Antenna Systems," *ibid.*, 1930, vol. 68, p. 1174.

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DISCUSSION ON

"FIELD TESTS ON THE 'GRID' TRANSMISSION LINES."*

Mr. J. A. Clegg (*communicated*): The results given in the paper of field tests on the "grid" transmission lines are of particular interest, in view of certain laboratory tests conducted at University College, London, under Prof. W. C. Clinton, on samples of the steel-cored aluminium conductors used on the grid system. The resistance and reactance of a double 100-ft. length, erected in a long passage and short-circuited at one end, were measured by means of a Gall-Tinsley co-ordinate a.c. potentiometer at various spacings, current densities, and frequencies, the corresponding d.c. resistance being also measured by the potentiometer method. These tests have some advantages over field tests in that greater accuracy in electrical measurement can be obtained, the effect of the steel core can be determined at the normal current-loading, and the internal inductance can be deduced more accurately, because tests can be made at various small spacings at which the internal inductance forms a larger proportion of the total inductance. The results of tests on the 30/·11 in. aluminium, 7/·11 in. steel conductor gave a d.c. resistance of 0·246 ohm per mile at 18° C., or 0·234 ohm per mile at 5° C., which compares with the author's figure of 0·235 ohm per mile at 5° C. for the Abernethy–Bonnybridge line. Alternating-current tests on this conductor gave the same value of the resistance, as against the author's figure of 0·232 ohm per mile. It would be interesting to know what experimental error the author would allow for stray losses in supports, etc. A test with a view to determining the stray loss in a line support and guard-ring showed a loss of about 1 watt with 100 amperes in the conductor, which would not produce on an actual line an appreciable rise in a.c. resistance. Standard tables give the resistance of this conductor at 15° C. as 0·249 ohm per mile, which apparently neglects the conductivity of the steel. The latter was taken into account in the laboratory tests quoted above, and it would be interesting to know whether in practice the connection at the end of the line is such as to give good electrical contact with the steel core. In determining the correction for inductance, the calculated inductance of the short-circuiting strip was subtracted from the total inductance, and the internal inductance was obtained by assuming the external inductance to be the same as for a homogeneous aluminium conductor of the same overall diameter. Thus an expression

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* Paper by Mr. J. S. Forrest (see page 85).

$$\left(0\cdot 41 + 2 \log_e \frac{D}{r}\right) 10^{-9} \text{ henry per cm}$$

was developed for the inductance of the conductor; but for large spacings, as the author states, it is sufficiently accurate to use the formula for a homogeneous aluminium conductor of the same overall diameter ($2r$). As far as theoretical considerations are concerned, the results are in fair agreement, for the problem approximates to that of a hollow stranded conductor if the longitudinal magnetization may be neglected, which would give an inductance of

$$\left(0\cdot 36 + 2 \log_e \frac{D}{r}\right) 10^{-9} \text{ henry per cm.}$$

To determine an approximate value for the longitudinal flux in the steel core, the voltage induced in a coil wound differentially (to avoid any effects due to the transverse flux) was measured on a sensitive valve voltmeter (consisting of a 2-stage low-frequency amplifier coupled to a grid-leak detector) which was calibrated against a standard mutual inductance of known constants. These tests showed a maximum total flux of about 50 magnetic lines of force with 100 amperes flowing in the conductor, but by treating the cable as a solenoid it is impossible to estimate exactly the effect of this flux on the internal inductance, owing to the fact that the radius of each strand is comparable with that of the core, so that it is impossible to estimate the flux cutting each strand. This flux is, however, insufficient to produce an appreciable rise in a.c. resistance. Results of tests on the earth conductor (12/·11 in. diameter aluminium 7/·11 in. diameter steel) at 50 frequency show that both the resistance and the inductance vary with the current-loading, giving at 100 amperes an increase in resistance of 5 per cent over the d.c. resistance and an increase in inductance of 15 per cent over that for a solid conductor having the same diameter. A determination of the flux in the core for this conductor showed a maximum value of about 500 lines at 100 amperes, which would give rise to an appreciable iron loss and an appreciable solenoid effect. The author points out that it is necessary to know the reactance and resistance in order to calculate the short-circuit currents, and it is therefore worth noting that at heavy current densities the constants of the earth conductor or of any single-layer conductor would be very different from those at normal loading. It would be interesting to know whether the author has any a.c. figures for the constants of the earth wire alone, for comparison with those obtained in the laboratory tests. Thus the author's tests indicate that the performance of the line can be calculated with sufficient accuracy, but that field tests are desirable as a precaution against faulty erection.

Mr. E. Parry (*communicated*): It is evident that the values of the electromagnetic and electrostatic inductions given on pages 90 and 91 have been considerably modified by the transpositions in both circuits, and by the presence of the earthing conductor. It would be both interesting and of considerable practical importance if opportunity could be found of measuring the electrostatic and electromagnetic inductions on, say, a single No. 14 S.W.G. wire placed parallel to the power lines at any convenient distance, e.g. 100 ft. The induction between a pair of power circuits and an isolated wire, or a pair of isolated wires running parallel thereto at a distance exceeding the height of the conductors above the ground, can be computed with a fair degree of accuracy, provided that the conductors of the power circuits are not transposed; and if the effect due to a pair of power circuits transposed in a definite manner were known, very important deductions could be made and applied to a wide range of conditions.

Mr. J. S. Forrest (*in reply*): Mr. Clegg's laboratory tests are of much interest and form a useful supplement to the field tests. The experimental errors in the resistance measurements given in Table 5 are about 1 per cent for the d.c. measurements and 2 per cent for the a.c. measurements, so that the d.c. and a.c. resistances of the Bonnybridge–Abernethy line are equal within the limits of experimental error. It would be expected that the losses in the supports of an overhead line would be negligible; Mr. Clegg's experiments confirm this. Various methods of jointing and clamping the lines are used, but the selection and design of the joints and clamps are governed more by mechanical than by electrical considerations, as it is easy to ensure that the electrical conductivity of the joint will be equal to that of the conductor, while it is by no means so easy to obtain the same mechanical strength in the joint as in the conductor. In the Bonnybridge–Abernethy and Abernethy–Dundee lines, Pairard joints are used in which the steel and aluminium are separately gripped between wedged cones, and the lines are "made off" with clamps of the bolted type in which direct contact is made only with the aluminium. It is considered that good electrical contact will be made with the steel core throughout the line, and the resistance measurements seem to indicate that this is the case. It is interesting to note that the value of the internal inductance which Mr. Clegg has deduced from his measurements can be derived theoretically by assuming that the distribution of the flux inside the conductor is the same as for a solid conductor but that all the current flows in the aluminium; it is doubtful, however, whether this is of much physical significance. No field tests have so far been made on the earth-wire alone; but it is important, from the theoretical aspect at least, to recognize that the constants of the earth conductor will be modified under heavy earth-fault conditions.

I agree with Mr. Parry that the values of the electromagnetic and electrostatic induced voltages referred to have been modified by the transpositions and by the presence of the earth wire respectively. The effect of transposition on the value of the electromagnetic induced voltage is briefly mentioned in the paper. As Mr. Parry remarks, much interesting information can be obtained from measurements of induced voltages on single wires and loops running parallel to the power lines, and it may be possible to carry out experiments of this nature at a future date. Measurements of the electrostatic induced voltage on near-by conductors would be especially interesting, as this quantity is extremely difficult to calculate with any degree of accuracy, owing to the presence of stray capacitances of unknown magnitude. As far as voltages induced by zero phase-sequence currents in the power lines are concerned, comprehensive tests have already been carried out in various countries at the instigation of the Commission Mixte Internationale.

INSTITUTION NOTES.

List of Members.

A number of copies are still available of the List of Members corrected to the 1st September, 1930. Any member wishing to receive a copy should apply to the Secretary.

Graduateship Examination Results: November, 1931.

SUPPLEMENTARY LIST.*

Passed.†

Anderson, I. L. (South Africa).
Beaglehole, K. (New Zealand).
Bhalla, B. B. S. (India).
Bhattacherjee, B. N. (India).
Bingham, J. M. (New Zealand).
Birdy, F. R. (India).
Bonny, A. G. A. (Brazil).
Butler, J. H. (New Zealand).
Chaudhry, S. S. (India).
Doshi, J. H. (India).
Ellis, R. H. (New Zealand).
Fyfe, R. J. (New Zealand).
Ganda, R. K. (India).
Ghose, N. C. (India).
Gray, C. M. (New Zealand).
Hughes, W. (New Zealand).
Iyer, K. P. (India).
Kapadia, P. M. (India).
Kapur, V. P. (India).
Khandhar, J. P. (India).
Lough, J. R. (New Zealand).
Manhire, M. A. S. (New Zealand).
Matchett, M. (South Africa).
Mehta, J. S. (India).
Mitchell, T. M. (Hong Kong).
Muir, W. L. (South Africa).
Murthy, B. R. (India).
Pappu, V. (India).
ParthaSarathy, N. E. (India).
Partridge, W. H. (South Australia).
Patel, B. J. (India).
Patell, R. J. (India).
Purohit, M. D. (India).
Rao, B. N. R (India)
Rao, B V. R. S. (India).
Rao, K. S. (India).
Sahgal, P. L. (India).
Sarup, S. (India).
Sethi, H. A. (India).
Shah, K. S. (India).
Simpson, G. R. (New Zealand).
Slevin, E. (New Zealand).
Smuts, W. B. (South Africa).
Stobie, J. C. (South Australia).
Torrance, A. E. (South Africa).
Varma, B. D. (India).
Vij, K. L. (India).

Passed Part I only.

Baines, J. C. S. (South Africa).
Canagarayar, R. (Ceylon).
de Mel, C. H. J. (Ceylon).
D'Lima, M. J. A. (India).
Joshi, N. K. (India).
Marathe, D. H. (India).
Marshall, G. C. (New Zealand).
Muir, J. S. (South Africa).
Pairman, R. (New Zealand).
Saggers, C. W. (New Zealand).
Shivram, T. M. (India).
Sinnathamby, S. P. (Ceylon).
Smith, J. W. (New Zealand).

Passed Part II only.

Bayley, R. H. P. (South Africa).
Cole-Baker, B. M. (New Zealand).
Cornfield, J. M. (India).
Dharap, P. W. (India).
Gupta, K. M. D. (India).
Laroia, G. S. (India).
Milne, M. R. (New Zealand).
Rao, N. S. (India).
Somayajulei, B. R. (India).
Young, R. C. K. (New Zealand).

Proceedings of the Wireless Section.

92ND MEETING OF THE WIRELESS SECTION, 4TH NOVEMBER, 1931.

Mr. J. M. Donaldson, M.C., President, took the chair at 6 p.m.

The minutes of the meeting of the Wireless Section held on the 6th May, 1931, were taken as read and were confirmed and signed.

A vote of thanks to Mr. C. E. Rickard, O.B.E., for his services as Chairman of the Section during the Session 1930–31, proposed by Mr. E. H. Shaughnessy, O.B.E., and seconded by Mr. G. Shearing, was carried with acclamation.

Col. A. S. Angwin, D.S.O., M.C., B.Sc.(Eng.), then delivered his Address (see page 17).

A vote of thanks to Col. Angwin for his Address was proposed by the President and, after being put to the meeting, was carried with acclamation.

The meeting terminated at 7.20 p.m.

93RD MEETING OF THE WIRELESS SECTION, 2ND DECEMBER, 1931.

Col. A. S. Angwin, D.S.O., M.C., B.Sc.(Eng.), Chairman of the Section, took the chair at 6 p.m.

The minutes of the meeting of the Wireless Section held on the 4th November, 1931, were taken as read and were confirmed and signed.

A paper by Commander J. A. Slee, C.B.E., R.N., Member, entitled "Reflection Methods of Measuring the Depth of the Sea" (see page 269), was read and discussed.

On the motion of the Chairman a vote of thanks to the author was carried with acclamation.

The meeting terminated at 7.55 p.m.

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* See page 294.

† This list also includes candidates who are exempt from, or who have previously passed, a part of the Examination and have now passed in the remaining subjects.

THE HIGH-VOLTAGE SYSTEMS OF ITALY.

By A. Dalla Verde.

(*Paper first received* 30*th April, and in final form* 13*th August,* 1931; *read before* The Institution 17*th December, and before the* North-Eastern Centre 14*th December,* 1931.)

Summary.

The paper gives a general review of the electrical plants of Italy.

Section (1) deals with historical development, especially in regard to legislation and the geography of the country.

In Section (2) the principal electrical undertakings are described and statistical data in regard to installed capacity and generation are given.

Section (3) deals with technical lines of development. The most important hydro-electric power stations utilize a high head, but there are a few interesting instances of low-head installations. Thermal power stations are in general designed to serve as reserves and to augment the hydraulic resources. Outdoor substations, built both of steel and of reinforced concrete, are becoming increasingly popular. Spun reinforced-concrete poles are also used for high-voltage lines, for example on a section of the 200-kV Isarco line.

Finally, methods of mechanical and electrical calculation are demonstrated, and details are given regarding the operation of the plant and lines.

(1) General.

The generation, transmission and distribution of electric power in Italy, which began towards the close of the last century, have developed rapidly and on a large scale, owing principally to the natural resources of the country, the initiative of industrial concerns, and sound legislation.

In 1894 Boselli's Bill compelled every property owner to allow overhead and underground electrical lines for industrial use to pass through his property. The law states that, before the construction of the line, compensation shall be paid to the owner to the extent that his property is reduced in value by reason of the line, the amount of compensation shall be agreed between the parties, and if agreement cannot be reached the exact sum shall be decided by the courts.

In cases where the line crosses or is in proximity to other public utility services, as, for instance, roads, railways, rivers, canals, telegraph and telephone lines, i.e. for practically all lines of any importance, the same law provides that it is necessary to obtain the previous consent of the Public Utilities Ministry (Office of Works), which, however, cannot refuse consent but has powers to enforce certain requirements to ensure public safety.

These laws, besides being very important at the time when they were made, embodied many interesting ideas and remained practically unchanged for over 20 years. Other laws governed the construction of central stations by regulating the use of water which was the property of the State; they also form the basis of the new Italian regulations now under consideration. The changes to be made to the old laws are intended solely to remove some inconsistencies in connection with certain particular questions. Even the recently-appointed ministerial committee for the co-ordination of electric lines has until now acted on the basis of the old regulations, leaving private enterprise unrestricted.

A few further details with regard to the mode of obtaining wayleaves in Italy may be of interest. The authority for a line—as for a hydro-electric plant—is equivalent to a statement of public utility; if there are any property owners with whom it is impossible to come to a friendly agreement, the Office of Works prepares a " consistency plan " (detailed list of lands and sums due for compensation) and submits it to the Prefect (local representative of the Government), who authorizes the occupation of the land or the wayleave. Before action is taken, however, the undertaker has to deposit at the " Royal Cassa Depositi e Prestiti " the sums due to the owners for compensation. As already stated, all disputes as to the amount due for indemnity are settled in the law-courts.

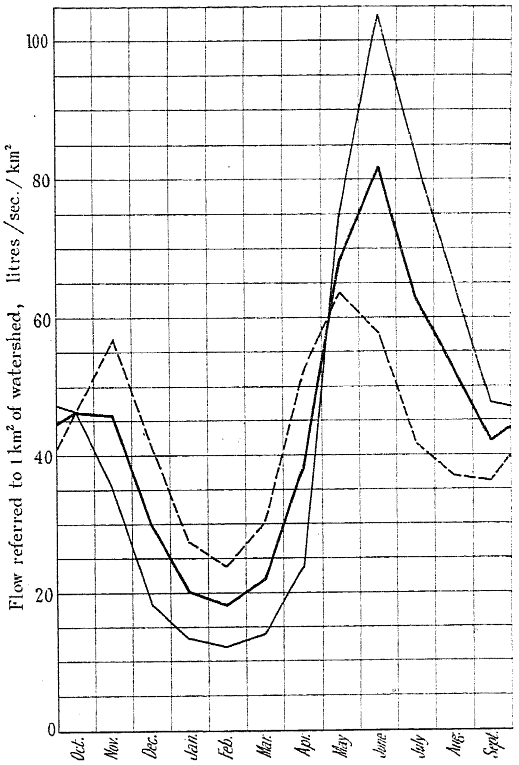

Fig. 1.—Alpine flow diagram.

——— Flow of typical Alpine river.
- - - - Flow of Alpine lake river.
━━━ Average flow.

To obtain the authorization decree, it is necessary to have the consent of all the interested public utility bodies; this, of course, means a great loss of time, and several months are sometimes necessary for a 100-km line. In cases of proved urgency the Ministry can adopt a shorter procedure (the permit for which is obtained in about a month) and give a statement, which has to be confirmed later by a regular decree, that the work is urgent and cannot be deferred. In such cases the Prefect can at once authorize the temporary occupation of the land. This holds good for two years, and if when this period has elapsed agreement has not been reached with the owner, the Office of Works and the Prefect are asked to give their assistance, as stated above. Whereas the occupation of the land is perpetual, the wayleave may be temporary (lasting for 60 years) but is generally perpetual also.

Unless there has been a special agreement, the landowner can at any time ask for the removal of the line, if he can prove that he wishes to have a building erected on the site. He is, however, compelled to put at the disposal of the company another equally suitable site. As regards the expenses incurred in the removal, the law is not clear on this point. Gardens and buildings may be crossed only after an agreement has been reached with the owner: the law does not allow of any compulsion in this respect.

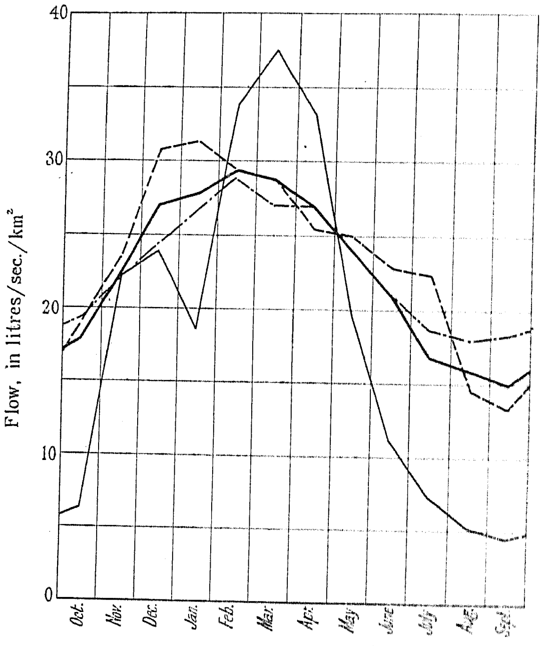

FIG. 2.—Apennine flow diagram.

—— Flow of River Sangro.
– – – „ „ „ Aniene.
– · – · „ „ „ Velino.
▬▬ Average flow.

Generally the indemnity is paid once and for all, but the amount varies greatly from place to place. As regards wayleaves, the average figure is 0·5 to 1·0 lira per metre length of the line, and the compensation for the space occupied by the supports is 5 to 10 lire for each wood pole, and 100 to 200 lire for each steel tower.

In Italy a law became necessary to facilitate the construction of transmission lines, as the lack of fuel compelled an increase in the ratio of the hydro-electric production to steam-power production of electricity. (At present this ratio is 100 : 3·55.)

Thanks to the foresight of the statesmen, Italian industrial concerns did not find insuperable obstacles in the way of their schemes, and at the end of last century they began to lay down the big plants that constitute the nucleus of Italy's electrical development. The plants at Paderno sull' Adda (1898), Vizzola sul Ticino (1900), Tivoli (near Rome), Ceres, etc., were all built at about that period; although wonderful judged by the standards of the time when they were constructed, these systems were only of local importance, being built to satisfy the needs of certain centres.

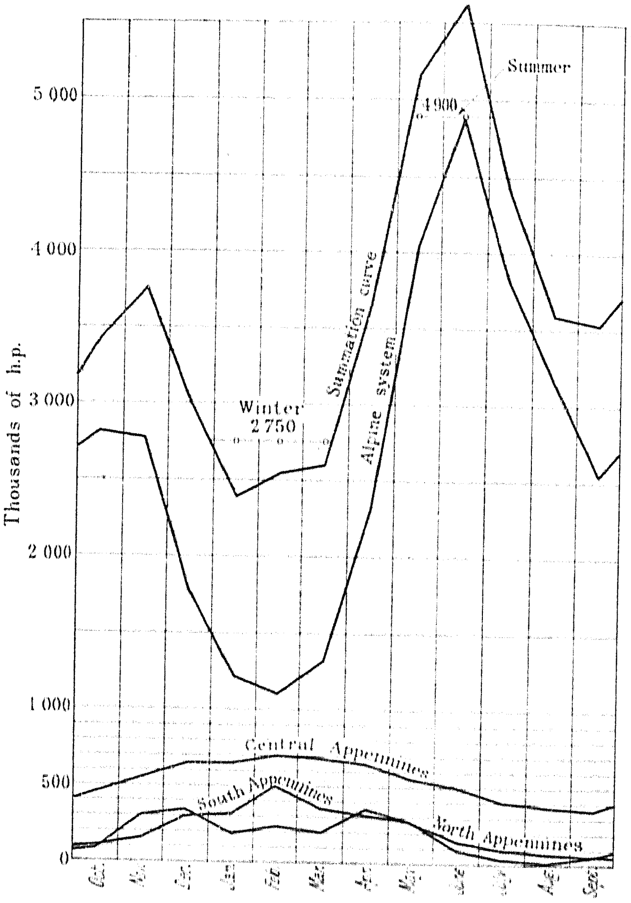

FIG. 3.—Total flow diagram.

Interconnection between the several districts either was not contemplated or was regarded as undesirable, as each company feared to allow any of the others to trespass upon its preserves. Supply undertakings preferred instead to maintain a "splendid isolation." This feeling was the cause of the difference (which still exists) in the frequencies employed by the several Italian plants.

The demand for electric power grew rapidly; in 1908 the figure of 1 000 million kWh per annum was reached, in 1914 it rose to 2 500 million, and in 1930 to over 10 000 million. The hydro-electric possibilities near big towns were rapidly exploited and it became necessary to go further away into the higher mountains, utilizing the waterfalls and either taking advantage of the natural reservoirs or building artificial ones. In this way the length of the lines was increased to hundreds of km; the transmission rating went up from hundreds to many thousands of kW, and in consequence the transmission voltages rose from 11 000–13 000 volts to 45 000 volts in 1906, 60 000 in 1910, 80 000 (Pescara plant) in 1912, 125 000 in 1922, 150 000 in 1929, and 200 000 (Isarco plant) in 1930.

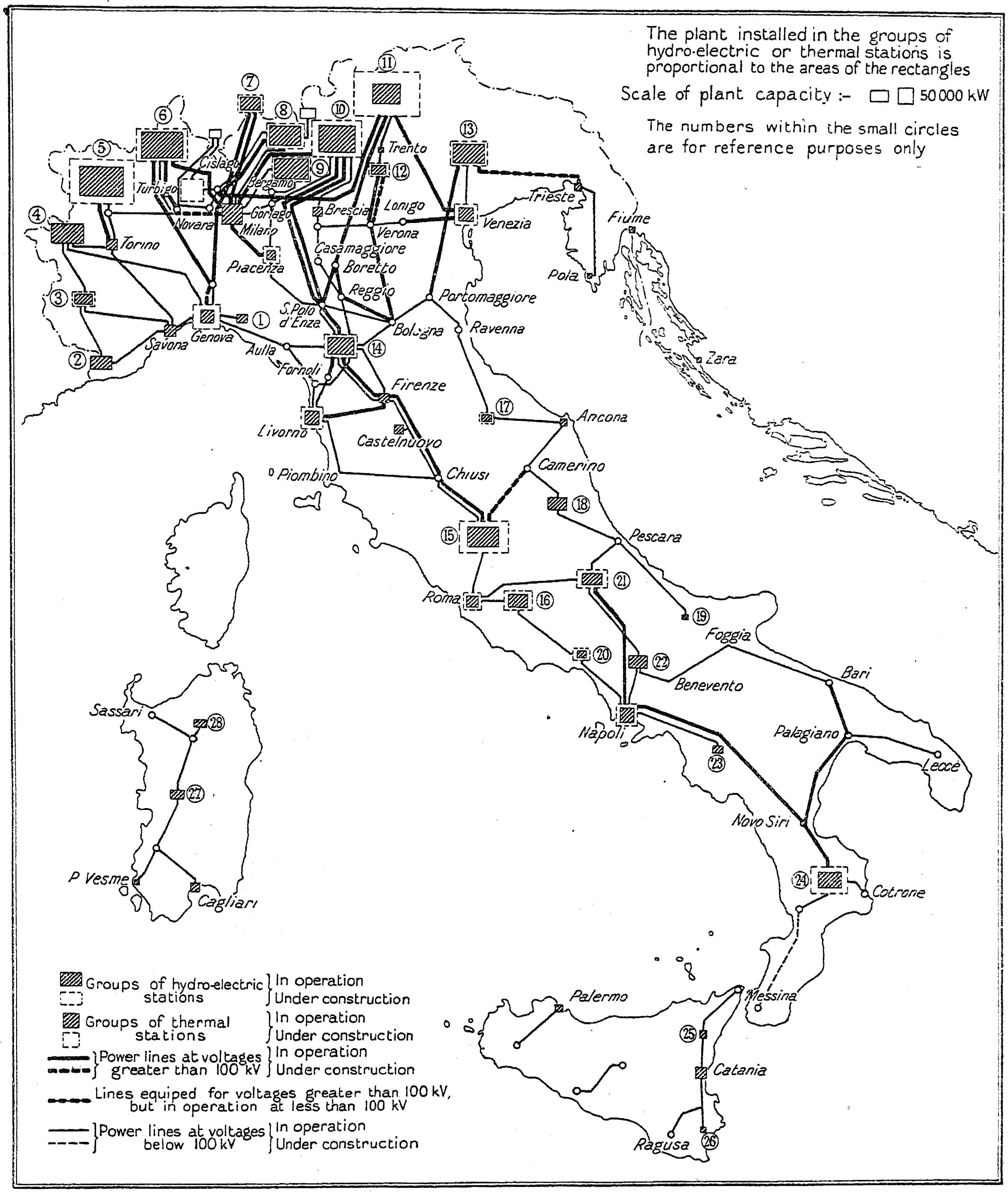
The plant installed in the groups of hydro-electric or thermal stations is proportional to the areas of the rectangles
Scale of plant capacity :- ▭ ▭ 50000 kW
The numbers within the small circles are for reference purposes only
▨ Groups of hydro-electric stations } In operation
⬚ } Under construction
▨ Groups of thermal stations } In operation
⬚ } Under construction
Power lines at voltages greater than 100 kV } In operation
} Under construction
Lines equiped for voltages greater than 100 kV, but in operation at less than 100 kV
Power lines at voltages below 100 kV } In operation
} Under construction
Trento
Trieste
Fiume
Pola
Zara
Cislago
Turbigo
Bergamo
Novara
Gorlago
Milano
Torino
Brescia
Lonigo
Verona
Venezia
Casamaggiore
Boretto
Piacenza
Reggio
Portomaggiore
S. Polo d'Enza
Genova
Savona
Aulla
Fornoli
Bologna
Ravenna
Firenze
Livorno
Castelnuovo
Ancona
Camerino
Chiusi
Piombino
Pescara
Roma
Foggia
Benevento
Bari
Napoli
Palagiano
Lecce
Novo Siri
Cotrone
Messina
Palermo
Catania
Ragusa
Sassari
P. Vesme
Cagliari
①
②
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Fig. 4.—Scheme of the Italian electric plants (reproduced from a report issued by the Public Utilities Ministry).

At the same time the convenience of interconnecting the various systems, with a view to exploiting further the differences between their curves of output and consumption, became evident. In this respect the connections between the Alpine and Apennine systems are particularly interesting.

The behaviour of the former (see Fig. 1) is typically Continental so far as the available water power is concerned; by contrast, the latter is of Mediterranean type (see Fig. 2). The two types of plant thus have features which more or less compensate each other, and the consequent advantages of their connection are quite evident.

It must be borne in mind, however, that the greatest amount of power is derived from the Alps, which have many rivers and a large number of great glaciers. These ensure the continuity of the sources of power and exhibit an interesting regularity due to the characteristics of the annual rainfall. In the Apennines, on the other hand, the major portion of the water power is located in only three of the principal districts—Umbria, Abruzzi and Calabria. In the remaining districts the rivers are less valuable owing to the large variations in rainfall from year to year. The principal centres of consumption being in Northern Italy, there is some compensation for the inferiority of the Apennines. The average theoretical output curve of the Alpine and Apennine power plants (1926) is shown in Fig. 3.

There are already some lines of interconnection running from North to South between the Alps and the Apennines, and others are in course of construction. There are also lines running from East to West interconnecting the various plants in the Alps, so as to compensate for the slight differences in the water flow of these plants. For instance, the Piedmont and Veneto plants (the latter being somewhat in advance of the former) are so connected, thereby allowing the excess energy produced in one district to be passed on to another, thus avoiding waste.

The chart in Fig. 4 shows the power transmission lines in Italy that lead to large substations in which equipment is provided for power-factor correction, paralleling between various power sources, effecting exchanges of power, metering, etc. It will be noted that there are several lines, worked at various voltages, following practically the same route and leading to the same centre. Although it is obvious that this situation is a consequence of the fact that the various lines were built at different and successive periods and sometimes with different criteria of merit, and although it is obvious that if the networks had to be rebuilt they would be differently planned, it must be agreed that the existing lines have not involved any waste. For a limited power demand it is impracticable to adopt high voltages, on account of the high cost of the line, equipment, and transformers. It is therefore better, at first, to use low-voltage lines. With the increasing demand for power the adoption of high-voltage lines becomes essential for adequate service of the lower-voltage networks, and the lower-voltage lines will serve the smaller towns that will develop gradually along the route. The existence of the two types of lines connecting the same centres is often justified also by the divergent routes taken, and constitutes a reciprocative reserve. Moreover, owing to their importance, the several plants from which the principal lines start must be able to feed several zones, and in addition, for safety reasons, big centres of consumption should be fed from several sources. The opinion of the Italian engineers being unfavourable to parallel operation of big systems, for reasons mentioned later, the existence of many lines is fully justified also from this point of view.

According to a report of the Ministerial Committee: "... Contrary to what is happening in other important countries, where the State had to promote the construction of power-line systems, in Italy this was done by the private industry itself, overcoming all technical difficulties."

The existence in Italy of different frequencies often causes difficulties in regard to interconnection of the various systems (see Fig. 5). A few years ago special committees thoroughly investigated the question of frequency standardization, and as they decided that the cost would be too high it was not carried out. Interconnection between plants was effected by means of frequency-changers, and, moreover, the new plants erected in the North were equipped with machinery adapted for the two frequencies most commonly used in Northern Italy, i.e. 42 and 50. Each plant usually operates at the frequency of its own system. In Southern Italy the frequency is 46. The possibility of overcoming the economic difficulties associated with frequency standardization is not, however, as yet entirely excluded.

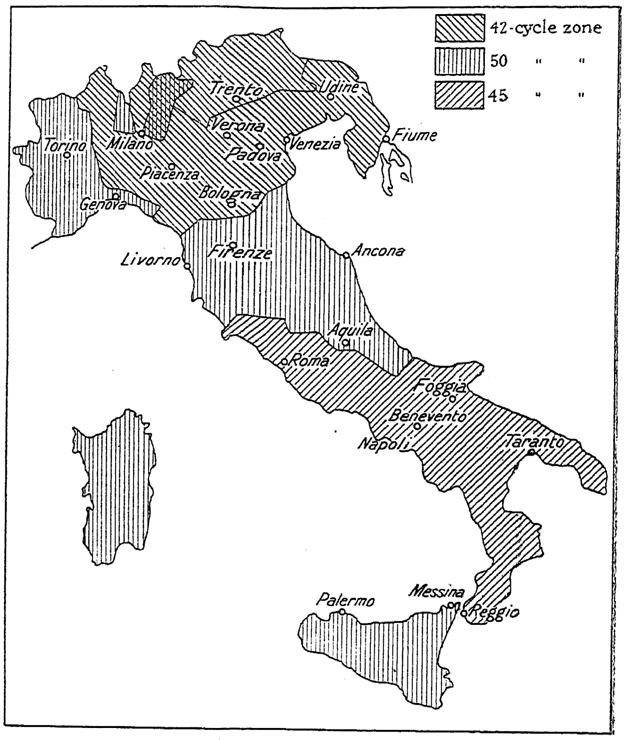

FIG. 5.—Frequency chart.

(2) THE ITALIAN ELECTRICAL UNDERTAKINGS.

In Italy, as elsewhere, the great development of the electrical industry which followed the War necessitated considerable capital expenditure. The cost of rebuilding the generation, transmission, and distribution plants, allowing only 2·50 lire per kWh, is about 25 000 million lire.

The above-mentioned causes brought about the amalgamation of separate undertakings into groups: little by little the small enterprises supplying only a few centres were eliminated, while a few big companies strengthened their position, greatly aided in this by national and foreign finance. These large groups now extend their activities over one or several districts, giving to the Italian electrical industry a particularly interesting aspect.

A recent report of Alessandro Taccani (chairman of the U.N.F.I.E.L., or National Union of Electrical Industries) mentioned the following groups (see Fig. 6):—

(A) Piedmont.
(B) Lombardy.
(C) Adamello.
(D) Venezia Tridentina.
(E) Adriatic.
(F) Tuscany.
(G) Central Italy.
(H) Southern Italy.
(I) Sicily.
(L) Sardinia.

(A) *Piedmont Group*.—This group operates hydro-electric stations in the Alpine valleys Moncenisio and Valle d'Aosta, and comprises the S.I.P. (Società Idroelettrica Piemonte), the Azienda Elettrica Municipale of Turin, the Cogne Hydro-electric Co., and a few other smaller concerns. It also owns the Società Lombarda per Distribuzione di Energia Elettrica, with stations on the Ticino, Valtellina, and Valle Brembana, its distributing zone being in West Lombardy. The principal distributing centre of the S.I.P. is Turin, which is served by several 60- and 125-kV lines. An important concentration point is Cislago, near Milan, upon which the 45- and 125-kV lines from Valtellina and the very important 200-kV line from Isarco (Bolzano) converge. In Cislago there is a connection with the Lombardy electrical system. The S.I.P. group has an annual output, including the energy it purchases, of about 2 000 million kWh and a plant capacity of over 500 000 kW. Moreover, it owns a very modern steam plant at Turbigo, near the Ticino, and others of minor importance.

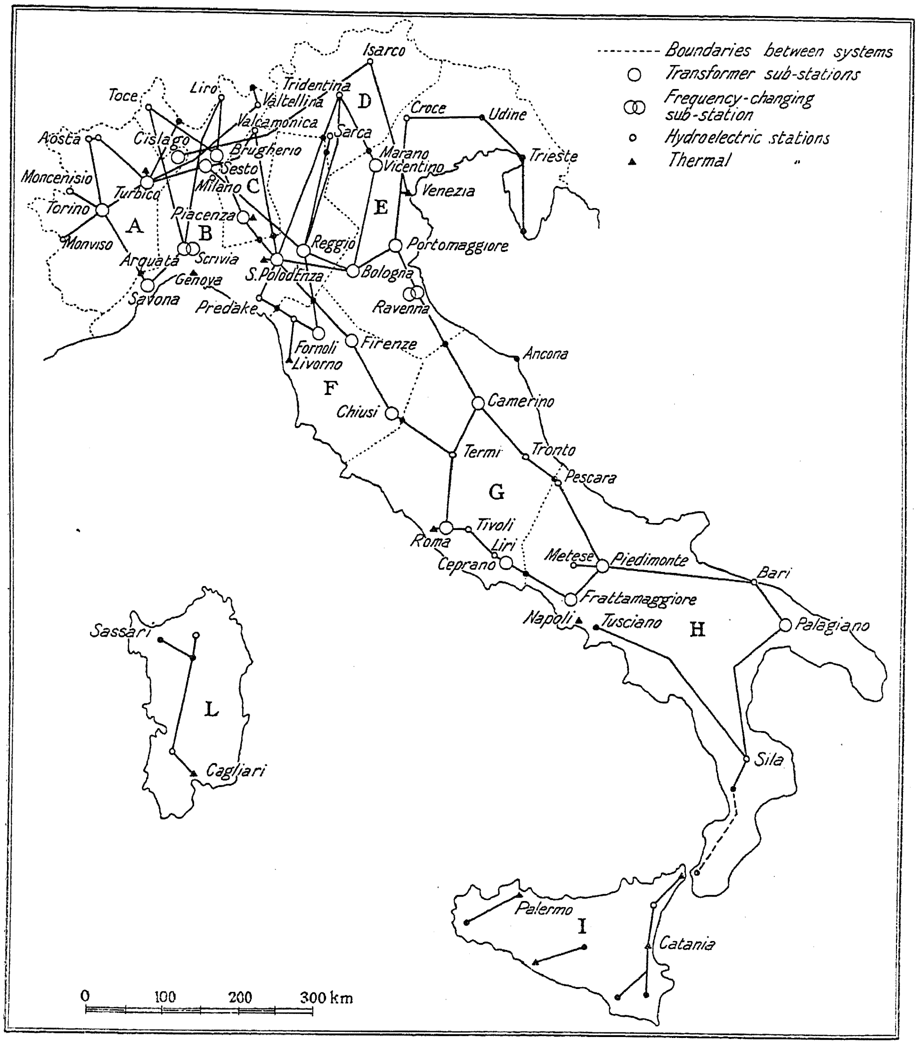

FIG. 6.—System chart (reproduced from a report issued by the U.N.F.I.E.L.).

A. Piedmont group.
B. Lombard group.
C. Adamello group.
D. Venezia Tridentina group.
E. Adriatic group.
F. Tuscan group.
G. Central Italy group.
H. Southern Italy group.
I. Sicilian group.
L. Sardinian group.

(B) *Lombard Group*.—This group has generating stations on the River Adda, in the Valle d'Ossola, in Valtellina, and in the Valli Bergamasche; it includes the companies of the Edison group, the Azienda Municipale of Milan, the plants of the Acciaierie e Ferriere Lombarde, etc. The Emilian and Ligurian groups with local generating plants are also connected to it. The principal distribution centres are Milan and Genoa, with several

60- and 125-kV lines. Among the more important substations are those at Brugherio, Arquata, and Reggio Emilia. The annual output of the Edison group, including energy purchased from other systems, amounts to 2 750 million kWh. Besides a modern steam station at Genoa, this group owns steam stations at Milan and elsewhere.

(C) *Adamello Group.*—This group operates stations in the Valle Camonica and the Emilian Apennines, connected with several 60- and 125-kV lines. The latter transmit power towards Milan and Tuscany; in S. Polo d'Enza there is a frequency-changer station interconnecting 42- and 50-cycle systems. The annual output of the Adamello group is about 650 million kWh, with a load capacity of over 200 000 kW. The reserve steam plant is at Piacenza.

(D) *Venezia Tridentina Group.*—Having stations in the valley of the Adige and district, this group is made up of the Societá Generale Elettrica Tridentina, Trentina di Elettricità, Idroelettrica dell'Isarco, Ponale, and other minor concerns. The network of 125-kV lines forming this system starts from near Trento and runs towards the Padana plain. It is connected to the Emilian system (at Reggio Emilia) and to the Adamello system (at S. Polo d'Enza). The 200-kV line with an east to west direction that terminates at Cislago connects the Isarco plant (Cardano) to the Piedmont system, and is extended to the East by the Valsugana line, which forms a connection with the Adriatic system. The Tridentina system will soon have a total output of 1 000 million kWh, with a load capacity exceeding 350 000 kW.

TABLE 1.

District	Length of line route, km				Length of circuits, km			
	30–50 kV	50–100 kV	Over 100 kV	Total	30–50 kV	50–100 kV	Over 100 kV	Total
Northern Italy ..	3 100	7 300	2 950	13 350	4 500	10 450	3 900	18 850
Central Italy ..	2 450	1 550	450	4 450	3 000	2 250	500	5 750
Southern Italy ..	1 550	1 100	250	2 900	1 850	1 900	250	4 000
Islands	300	300	—	600	300	600	—	900
Total	7 400	10 250	3 650	21 300	9 650	15 200	4 650	29 500

(E) *Adriatic Group.*—This group owns a number of 60- and 125-kV lines that gather the output from the stations at Piave (S. Croce), Cellina, and Cismon, and transmit to Venice and Bologna (through the substation of Portomaggiore), joining up with the Adamello and Emilian systems. Several other lines feed Venezia Giulia (Trieste). The energy output is over 800 million kWh and the load capacity is more than 250 000 kW. At Marghera (Venice) there is a steam-power station for reserve purposes belonging to the Società Adriatica di Elettricità group of companies.

(F) *Tuscan Group (Florence).*—This group forms the compensating centre of the Alpine and Apennine power plants. It operates small hydro-electric stations and is connected by important 125-kV lines to the Adamello and Adriatic systems on the one side and to the Central Italy system on the other. The modern steam station of Leghorn can, if necessary, supplement the output.

(G) *Central Italy Group.*—This group has generating stations in the Umbro Apennines and on the Liri, and also a steam station in Rome. It comprises the plants of the Central Electric group, the Società Terni, and the Azienda Elettrica of the Governatorato of Rome. The greater part of the power is produced by the Acquoria and Galleto (Terni) stations, and is transmitted by 125- and 60-kV lines to Tuscany, Marche, and Rome. When the plants are completed the output to be transmitted will be about 1 000 million kWh per annum, and the load capacity will be approximately 280 000 kW.

(H) *Southern Italy Group.*—This takes in all Southern Italy, and has stations in the Abruzzese Apennines (Pescara), Irpino (Matese, etc.), and Sila; it also owns a steam station at Naples. Besides the companies of the Società Meridionale di Elettricità group, it includes the Azienda Elettrica del Volturno. A number of 80- and 150-kV lines transmit power from the Pescara station to the substation at Frattamaggiore (near Naples), the 150-kV lines from Sila are connected to the substation at Tusciano, and other lines worked at this voltage and at 60 kV feed the Puglie (Palaggiano) substation. The annual output of the whole system is about 1 000 million kWh, the load capacity being over 350 000 kW.

TABLE 2.

District	Voltage			Total
	30–50 kV	50–100 kV	Over 100 kV	
	kVA	kVA	kVA	kVA
Northern Italy	559 000	1 155 000	328 000	2 042 000
Central Italy	202 000	366 500	59 000	628 000
Southern Italy	40 000	256 000	15 000	311 000
Islands ..	21 000	21 000	—	42 000
Total ..	822 000	1 798 500	402 500	3 023 000

(I) *Sicilian Group.*—This is formed by the hydro-electric plants of Belice, Cassibile, and Alcantara, of the

Società Generale Elettrica della Sicilia, to which belong also the steam stations of Palermo and Catania. A 60-kV line network distributes power; in 1930 the output was about 140 million kWh.

(L) *Sardinian Group.*—This comprises the hydro-electric plants of Tirso and Coghinas, and the steam station at Cagliari of the Società Elettrica Sarda. The output for 1930 was about 140 million kWh and was carried by 60-kV lines.

Besides these industrial systems there are the plants operated by the Italian State Railways, which produced a total of over 120 million kWh in 1928 and have several 60- and 125-kV lines.

Table 1, which was prepared by the Hydrographic Service of the Public Utilities Ministry, gives particulars of the lines with voltages of 30 kV and upwards which had been built and were in operation by the beginning of 1928. During the last three years (1928–1930) there has been an increase of 20 per cent, so that 35 000 km (20 000 miles) of high-voltage circuits are now in operation.

Table 2 gives the kVA capacity in 1928 of transformers installed in substations fed by lines operated at voltages of 30 kV and upwards. It is estimated that during the last three years there has been an increase of 20 per cent in the capacity of the transformers installed in the big Italian substations, giving in 1930 a total of 3 600 000 kVA.

Table 3 gives the capacity of machinery installed in the Italian power stations and Table 4 gives their output. Both sets of statistics apply to the year 1930 (U.N.F.I.E.L.).

Assuming that the plants the outputs of which are not included in Tables 3 and 4 (plants used by industrial concerns for their own specific purposes) produced about 1 000 million kWh during the year, the total electric power production of Italy was about 11 000 million kWh.

TABLE 3.

		North	Central	South	Islands	All Italy
		kW × 10^3	kW × 10^3	kW × 10^3	kW × 10^3	kW × 10^3
Installed capacity as at Dec. 31, 1930	Hydro-electric	2 900	590	310	80	3 880
	Steam	454	193	78	43	768
Total	.. ..	3 354	783	388	123	4 648

TABLE 4.

		North	Central	South	Islands	All Italy
		kWh × 10^3	kWh × 10^3	kWh × 10^3	kWh × 10^3	kWh × 10^3
Production of power in 1930 ..	Hydro-electric	6 970 484	1 582 393	955 988	212 598	9 721 463
	Steam	102 511	106 554	24 192	70 218	303 475
	Imported	164 070	—	—	—	164 070
Total	.. ..	7 237 065	1 688 947	980 180	282 816	10 189 008

As regards the probable future production capacity of the Italian hydro-electric plants, it was stated recently by Messrs. Marinoni and Testa, who have made a study of this subject for the U.N.F.I.E.L., that 32 000 million kWh could be economically generated from available water-power sources, equivalent to three times the power generated at present.

(3) LINES OF DEVELOPMENT OF HIGH-VOLTAGE PLANT IN ITALY.

A general feature of the Italian plants which is particularly evident to Anglo-Saxon and American engineers is the great number of types of construction employed; these are often quite different from those used elsewhere. Besides being a consequence of the rather restless character of the Latin spirit, this is due to the way in which the plants were gradually developed.

At present a large-scale programme of technical standardization is being carried out by the A.E.I. (Associazione Elettrotecnica Italiana) and the U.N.F.I.E.L., and a greater uniformity of design will undoubtedly be achieved in the future. Although this will bring many economic advantages, it will lead to a loss of variety from the technical point of view. The following are a few of the factors which guide designers of power plant and will probably be incorporated in the technical regulations now under consideration.

Voltages.—As regards voltages of 30 kV and upwards, a distinction must be drawn between high-power distribution and high-power transmission lines. For the former, voltages of 30 and 45 kV are employed, whilst for the latter, voltages of 60, 125, 150 (in Southern Italy), and 200 kV are adopted. A transmission voltage of 80 kV is only employed in a few instances (Pescara and the Azienda Elettrica Municipale of Turin). The use of 125-kV lines is now being greatly developed; 200-kV lines are reserved for the transmission of very large amounts of power, and as yet the single-circuit line (partly double-circuit) from Cardano to Cislago is the only one on which this voltage is employed. This line, which is 242 km (150 miles) in length, has a normal load of 120 000 kW and a maximum load of 150 000 kW. The above-mentioned voltages represent average values at the receiving end; at the generator the corresponding figures are up to 20 per cent higher. The insulation of the lines is generally based upon the generator voltage.

Power Plants.—Although a detailed consideration of the power stations is rather outside the scope of this paper, a few remarks on the subject may be useful in so far as they serve to complete this general review of the Italian high-voltage systems.

The greater number and the most important of the hydro-electric plants operate at a high head (exceeding 50 m, or 150 ft.). The important plant with the greatest head (1 100 m, or 3 610 ft.) in Europe (see Fig. 7, Plate 1) belongs to the Moncenisio system (Venaus), where three machines each of 18 000 kW are installed; the reservoir of this plant has a capacity of 30 000 000 m^3 (1 060 million cub. ft.). The present largest Italian power station (see Fig. 11, Plate 2) is at Cardano, on the Isarco, where five 30 000-kW groups (Francis vertical turbines, 252 to 300 r.p.m., 42 to 50 cycles per sec.) and three 10 000-kW groups (Pelton vertical wheels, 4 or 5 nozzles, 250 r.p.m., $16\frac{2}{3}$ cycles per sec.) are installed, the latter being for railway use. The head is 155 m (510 ft.); there are five pipe lines each with a diameter of 2 · 80 m (about 9 · 20 ft.), and one with a diameter of 2 m (about 6 · 5 ft.). In the other big power station—the Galleto (Terni) station—the equipment, when complete, will consist of ten 40 000-kW groups driven by Francis vertical turbines and utilizing a head of 197 m (650 ft.). Other modern plants operating at high head include those at Marmore (Piedmont), Liro (the Mese station, near Chiavenna), Piave (Santa Croce), Ponale, Sila (the Ampollino station, in Calabria), etc., each of which has a capacity of over 50 000 kW.

Owing to the geographical characteristics of Italy, the plants having a large stream flow and a low head are of less importance. In this class, however, there are a few noteworthy stations, e.g. the historical plants at Paderno (on the Adda) and Vizzola (on the Ticino). Of great interest also is the plant at Mori (on the Adige), where 5 000-kW Kaplan turbines are employed, the head being 10·8 m (35 ft.), the flow 50 m^3 (1 800 cub. ft.) per min., and the speed 150 r.p.m. In Sardinia there are some interesting power stations in this class, for example the underground station at Coghinas and another at Tirso; the latter utilizes a reservoir of 400 million m^3 (14 100 million cub. ft.) capacity.

The modern tendency in Italy—as also, for that matter, throughout the world—in regard to machinery is to install large units. The 40 000-kW vertical groups of the Galleto station (see above) are an example of this; among the horizontal groups, those of 33 000 kW [Pelton wheels for 520 m (1 710 ft.) head, 500 r.p.m., 2 nozzles] at the Ponale station are worthy of mention.

Regarding the power stations the prime movers of which are steam-driven, in Italy these are, as already mentioned, designed to serve as reserves and complementary to the hydraulic resources, so that the fullest use may be made of the latter. In modern plants the steam pressure at the boiler is between 30 and 35 kg per cm^2 (425 to 500 lb. per sq. in.); the temperature of the steam is 350 to 425° C. (660 to 800° F.); the heating surface of the boilers is from 1 000 to 2 000 m^2 (10 800 to 21 500 sq. ft.); the capacity of the turbines is between 15 000 and 30 000 kW, with speeds of 1 500 and 3 000 r.p.m., generally two or three cylinders are connected in tandem-compound (at Leghorn, 14 000-kW Ljüngström turbines are installed).

Electrical Machinery.—Without entering into details of construction, it may be mentioned that the generation voltages commonly used are 6, 8, and 11 kV, with a tendency towards higher values for larger ratings. The alternator voltage of the Subiaco plant, built about 1906, is 30 kV, but this is the only instance of so high a value being used.

Transformers.—In Italy there is no absolute preference for either 3-phase units or banks of single-phase units; generally the choice is made for each individual case, taking into account the requirements as regards spare parts, possibility of transport, space, etc. There is, however, a slight preference for 3-phase transformers, especially in those power stations where space may be limited; a particular instance is that of the above-mentioned Cardano power station, where each 36 000-kVA alternator has a 3-phase transformer of the same rating, raising the voltage to 240 kV for the line which connects with Cislago. At the receiving end of this line, on the other hand, four single-phase transformers for stepping down the voltage from 200 kV to 45 kV are installed, one of these being for reserve purposes. These transformers have three windings—for 20 000, 25 000, and 15 000 kVA respectively. Three-winding transformers are very largely employed at the receiving ends of lines, in the substations, for use with the synchronous or asynchronous motors which are now being widely adopted both in Italy and elsewhere for power-factor and voltage control.

In regard to the methods of cooling large transformers, water-cooling is still the most popular, by means of oil circulation in tubular coolers for sizes above 10 000 kVA; for transformers of smaller capacity, cooling coils in the transformer tank are generally used instead. The various forms of the air-blast cooling system are, however, now coming into more common use. This method has the advantage of eliminating all the trouble due to water-pits and pumps, cooling towers, ponds, etc. Although it is more expensive, it allows a greater flexibility during periods of overload. The 200-kV transformers mentioned above are air-blast cooled; in those at the Cardano power station the oil circulates in tubular coolers having tubes of elliptical section exposed to cold air blown by special blowers; at the Cislago station, on the other hand, the transformer tanks have radiators on to which the cooling air is blown, after being led through perforated pipes. For very high voltages, where even small quantities of water in the oil can be troublesome, the air-cooling method will probably have to be adopted.

Lay-out of Electrical Apparatus.—With regard to the lay-out of the electrical apparatus, a distinction must

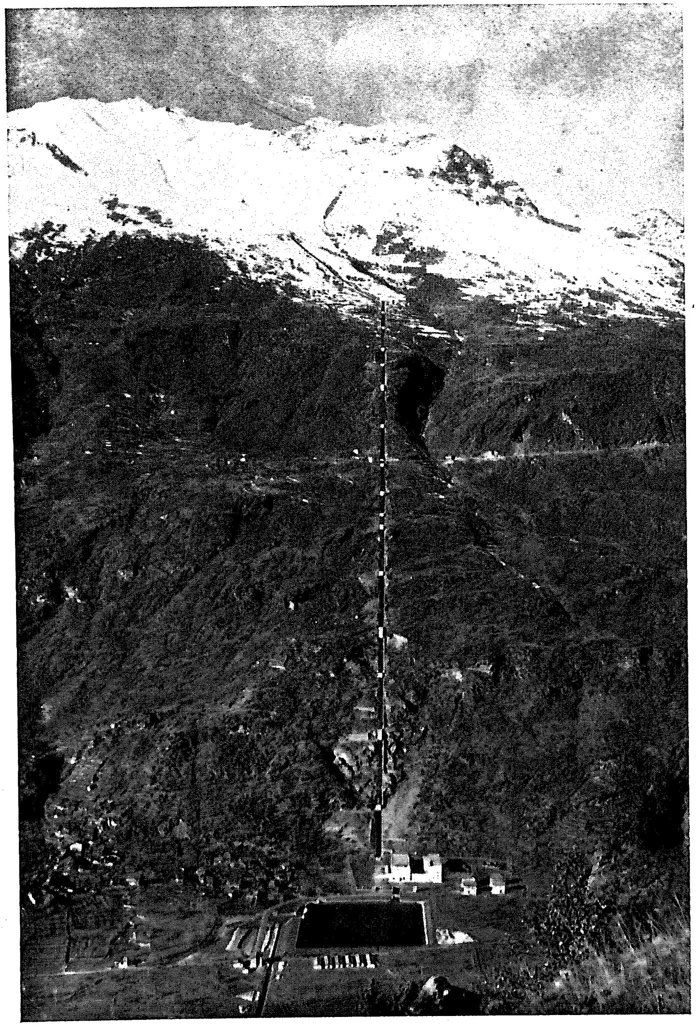

FIG. 7.—Venaus power station.

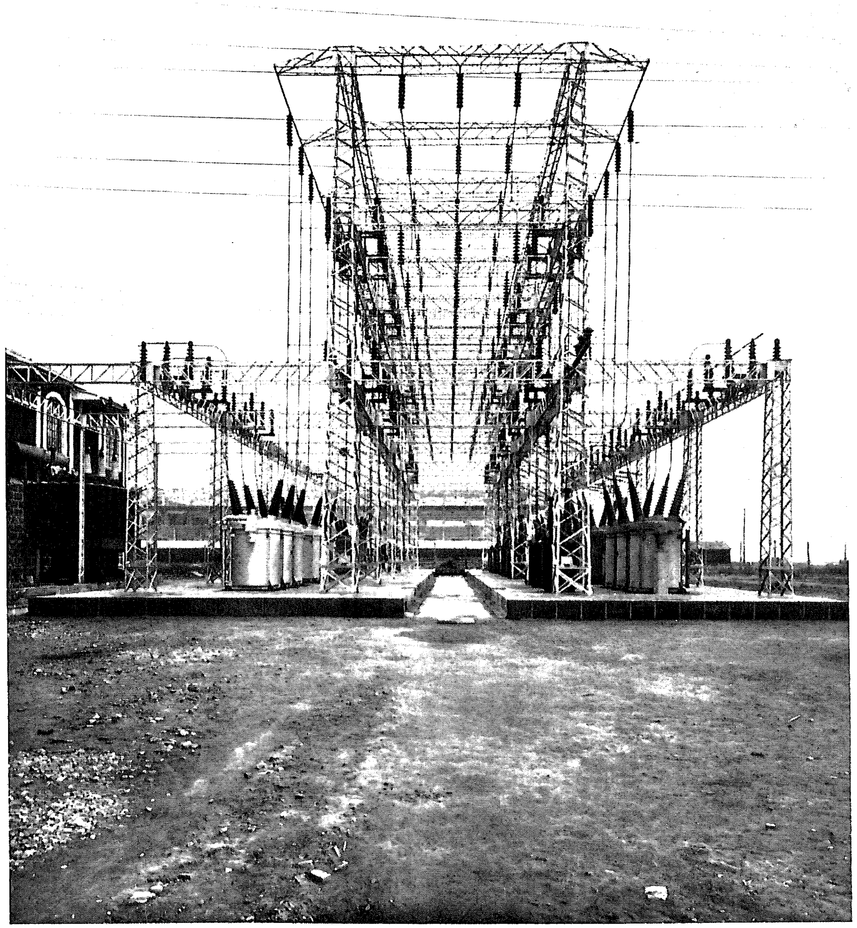

FIG. 8.—Marghera substation (150 kV).

Plate 2.

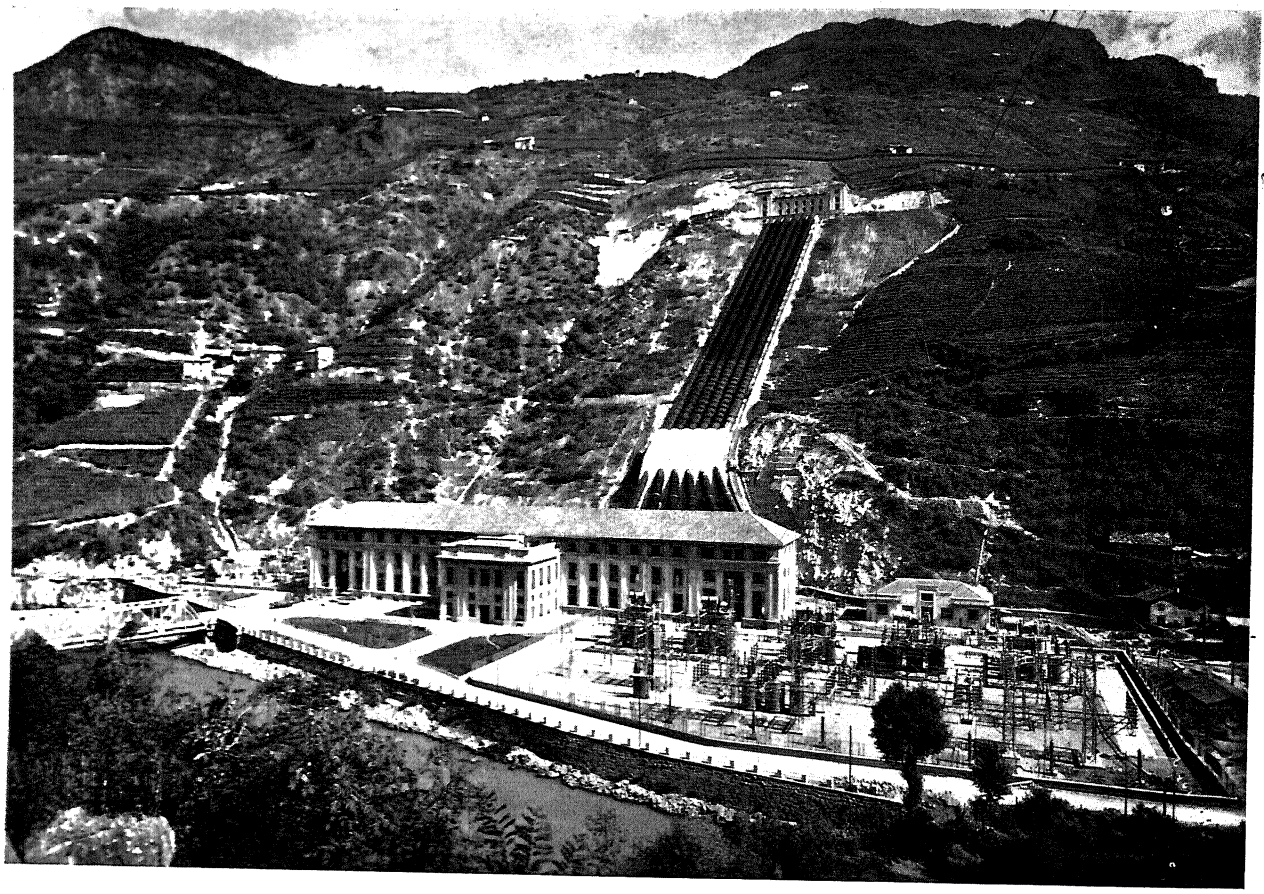

Fig. 11.—Cardano power station.

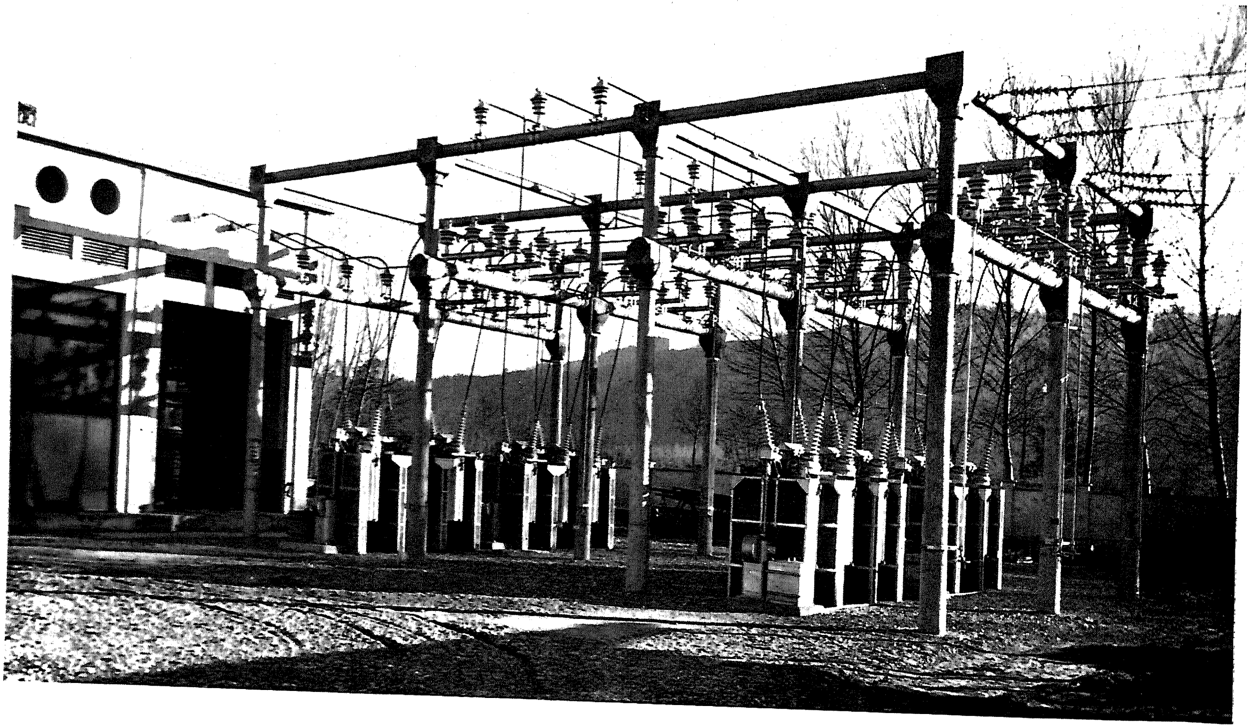

Fig. 12.—Chivasso substation.

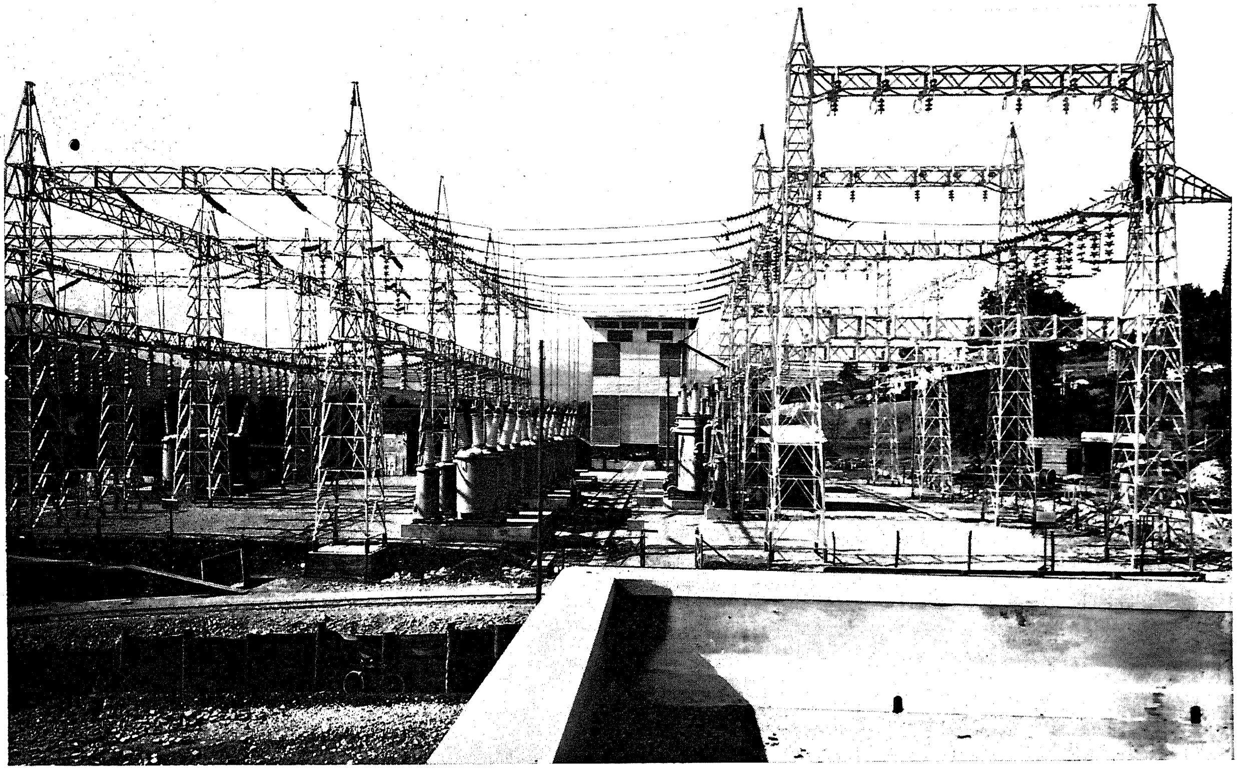

Fig. 13.—Frattamaggiore substation (150 kV).

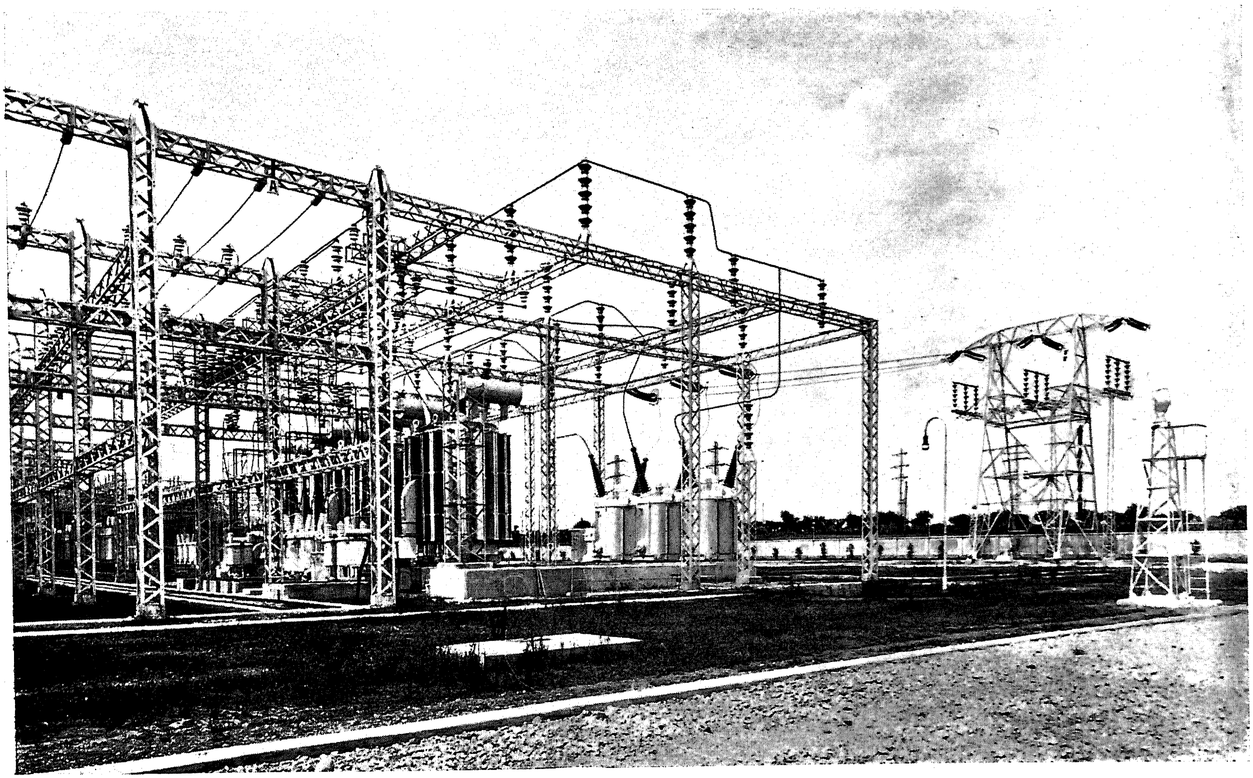

Fig. 14.—Cislago substation (200 kV).

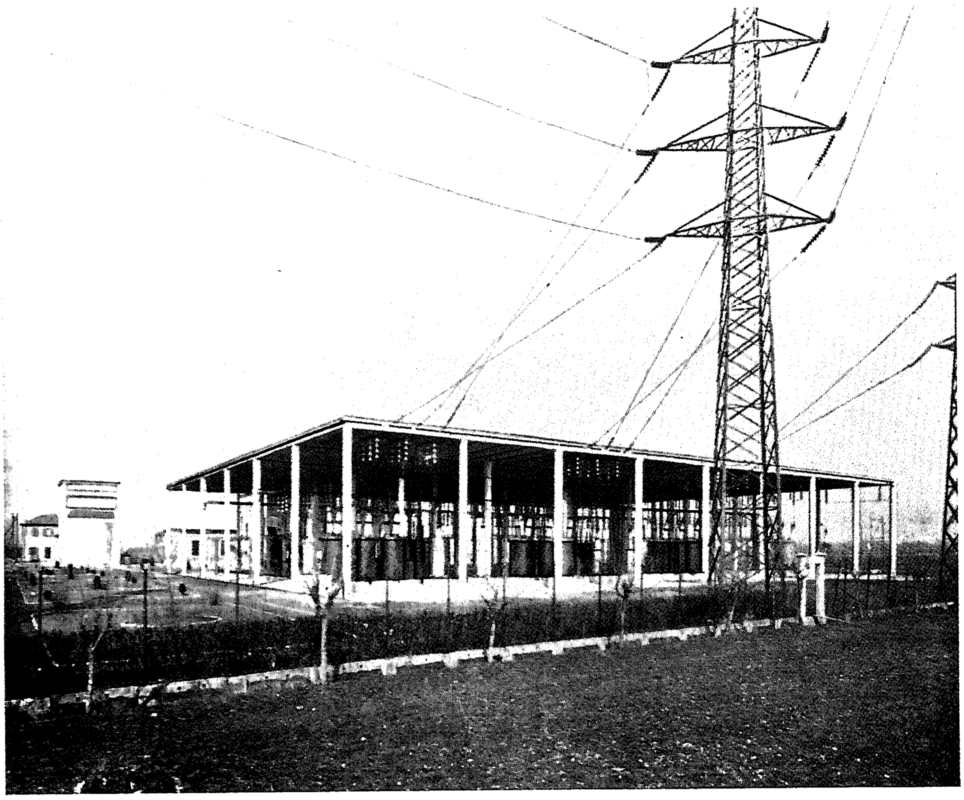

FIG. 15.—Brugherio substation.

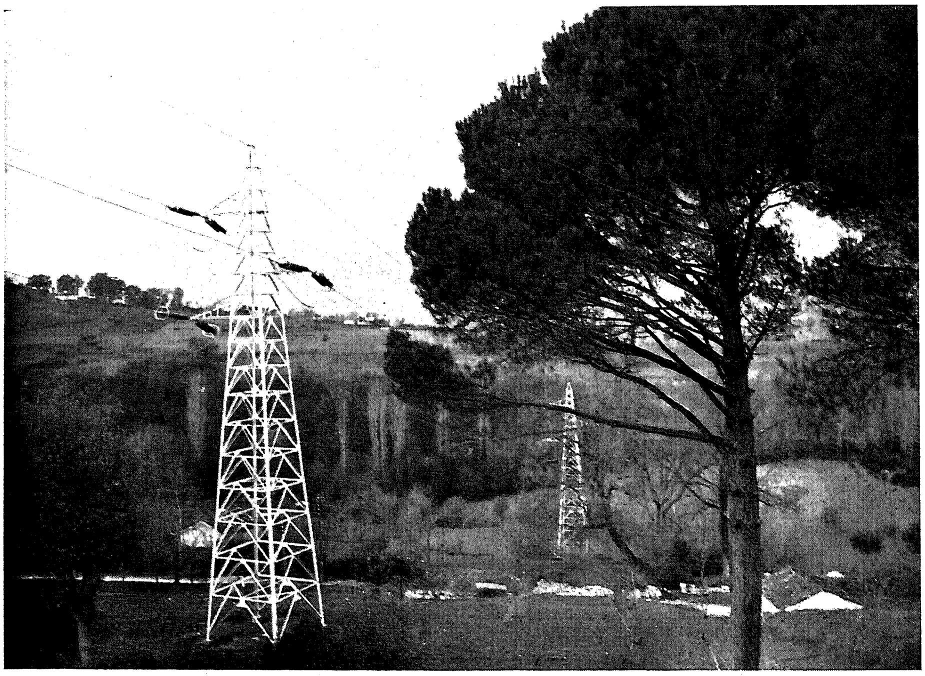

FIG. 20.—Towers used in Southern Italy (150 kV).

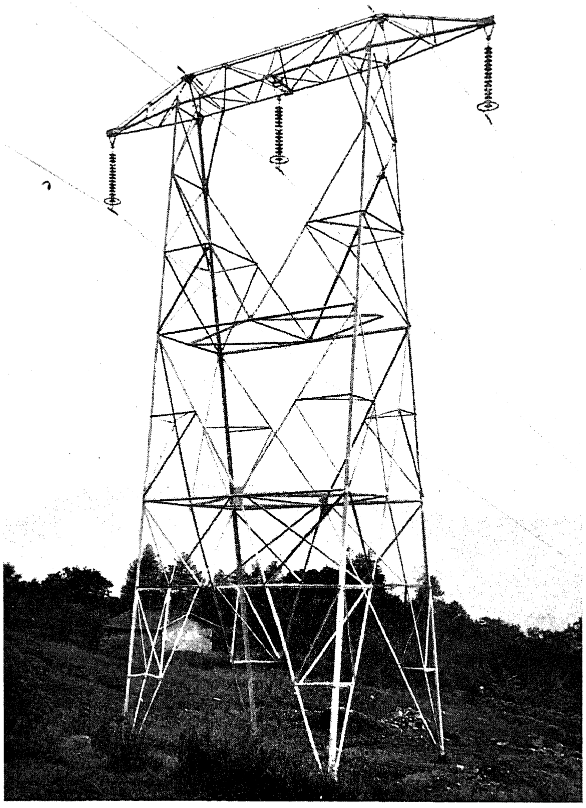

FIG. 22.—Towers used on Isarco line (200 kV).

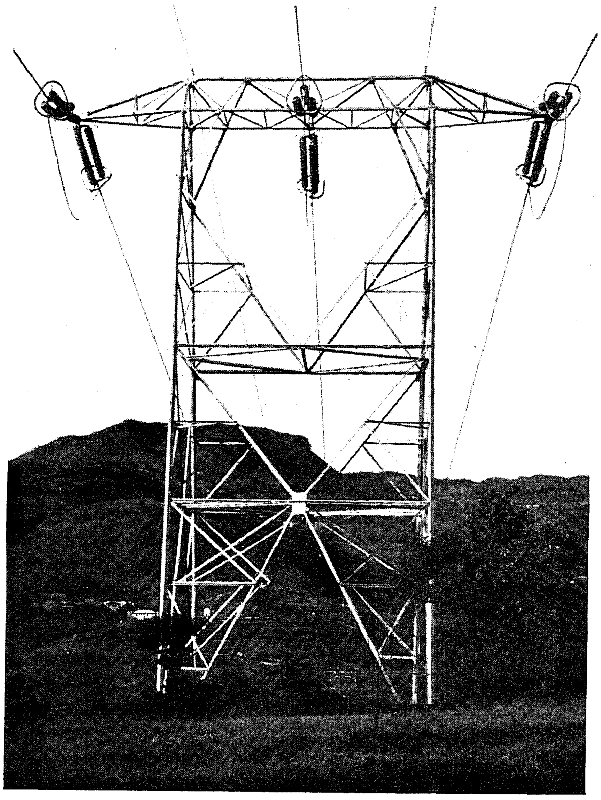

FIG. 23.—Towers used on Isarco line (200 kV).

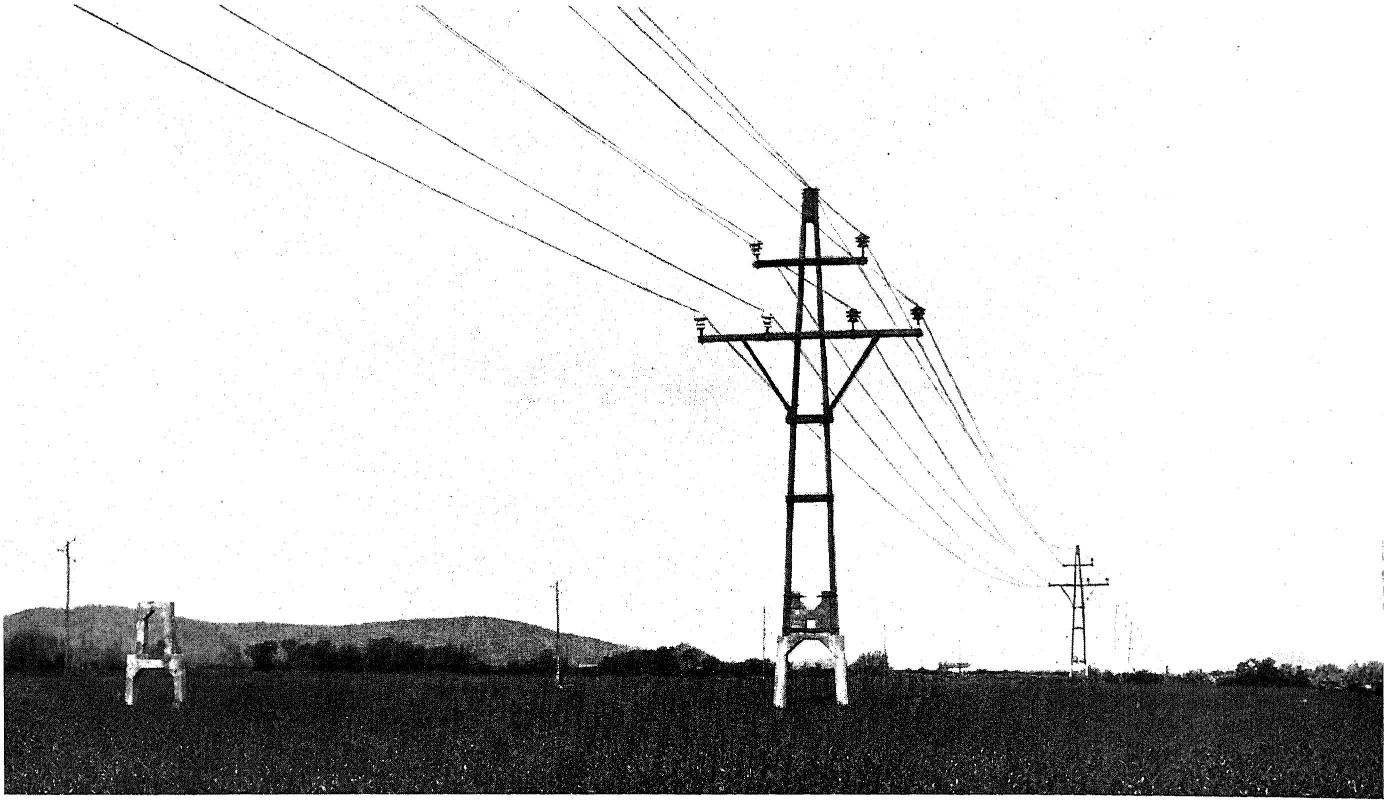

FIG. 24.—Poles used in Sardinia (60 kV).

Plate 6.

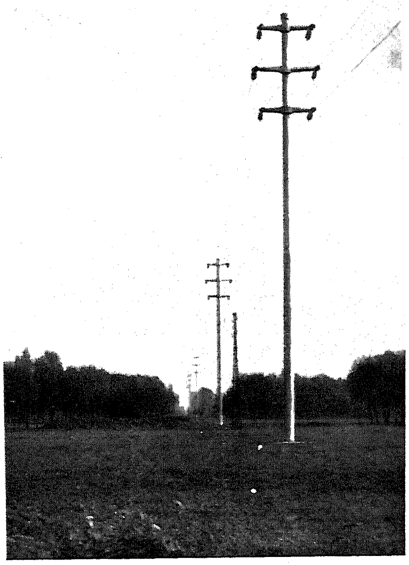

FIG. 25.—Spun reinforced-concrete poles.

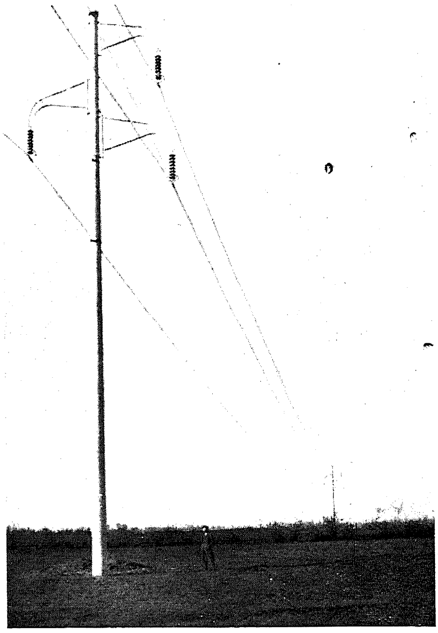

FIG. 26.—Spun reinforced-concrete poles.

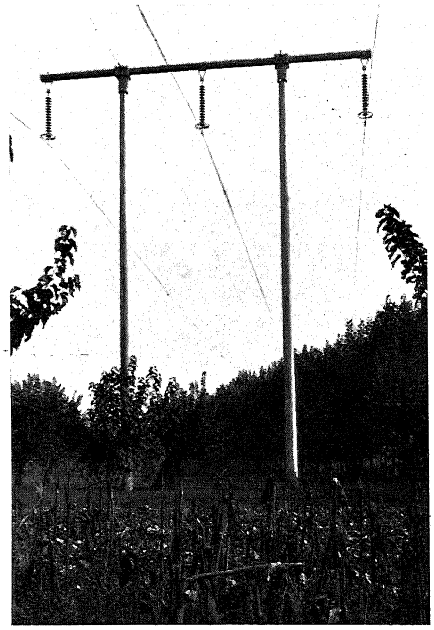

FIG. 27.—Spun reinforced-concrete poles used on Isarco line.

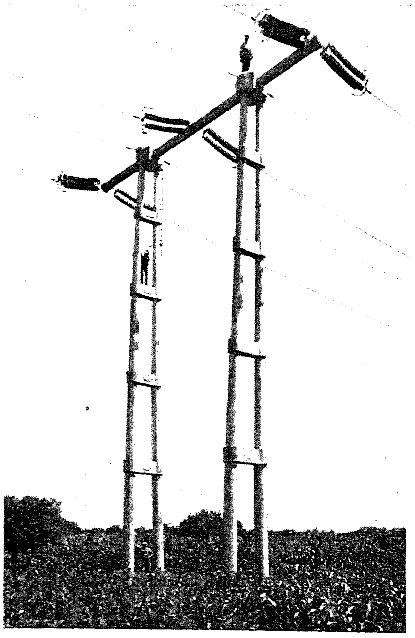

FIG. 28.—Spun reinforced-concrete poles used on Isarco line.

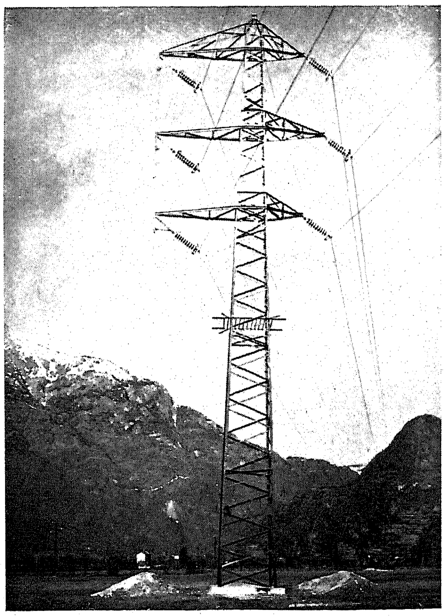

FIG. 30.—Special tower used on Covalou–Turin line (125 kV).

be drawn between the low-voltage and the high-voltage sections. For the first, where the phenomena due to current have a predominant effect, the general tendency is to install the various pieces of apparatus in separate compartments, so as to divide from the busbars, disconnecting switches, wiring, etc., all the oil-containing parts where there is danger of explosion. Owing to the rather small size of Italian plants in comparison with those of other countries (e.g. America), there is no definite separation between the phases. Greater care is, however, taken to reduce the result of such troubles as the entry of oil or dirt into the various parts of the plant. Thus the cells of the oil circuit-breakers open on to the outside of the building and means are provided to carry away any oil that may be thrown from the tanks.

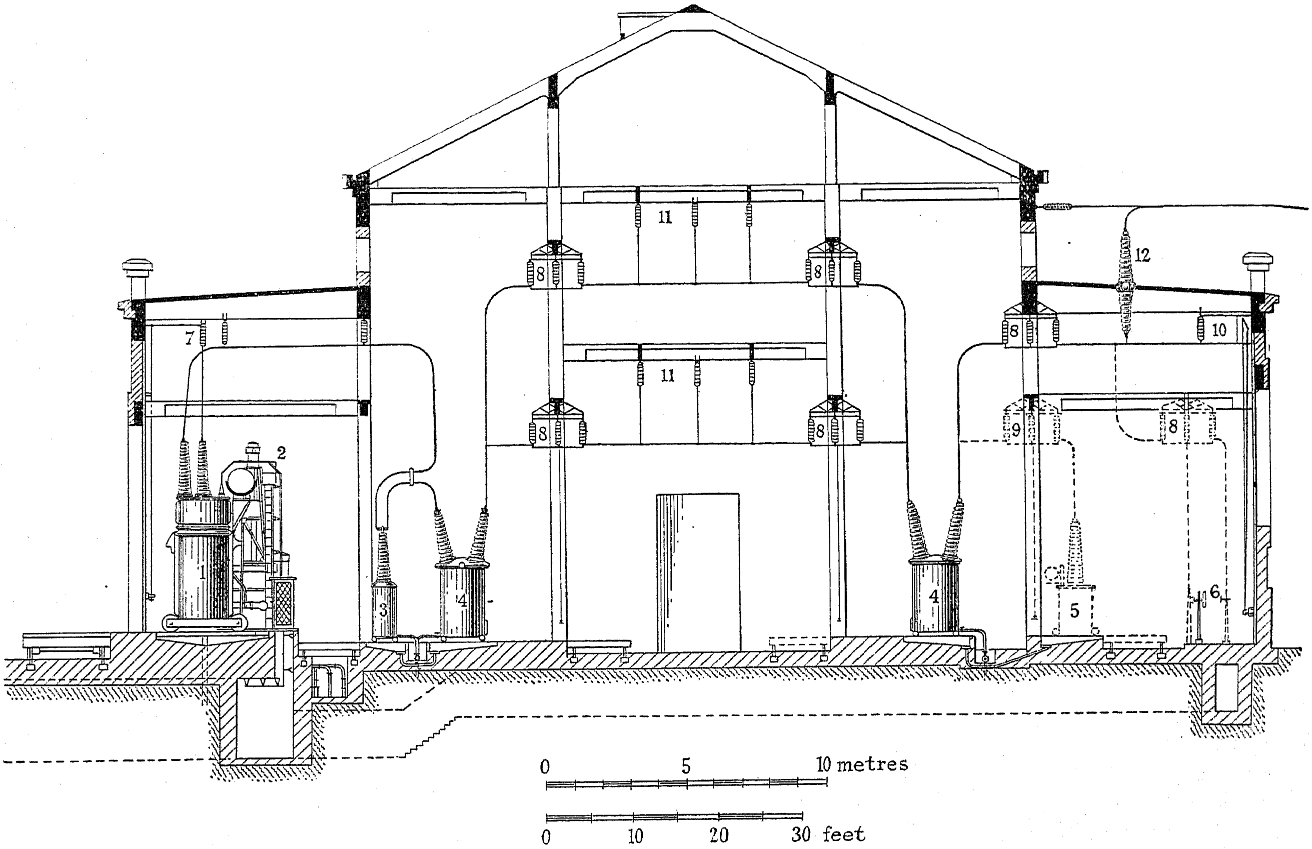

FIG. 9.—Part of 130-kV substation at Mese.

1. Three-phase 30 000-kVA transformer.
2. Circulating pump and oil cooler.
3. Current transformer.
4. Circuit breaker.
5. Single-phase potential transformer.
6. Electrostatic voltmeter.
7. Single-pole isolating switches.
8. Triple-pole ,, ,,
9. Double-pole ,, ,,
10. Earthing knife switches.
11. E.H.T. busbars.
12. Bushing insulators for outgoing lines.

For the high-voltage apparatus, from 45 kV upwards, the methods used are quite different; also for indoor installations great care is taken to simplify the lay-out. For 60 kV the 2-storied arrangement is the most common, and the lightning arrestors that were widely used at one time are being discarded. As a further step towards simplification, single-story buildings are employed: in this way the "halle" disposition, which is typical of many of the Italian 125- and 150-kV plants, is obtained (see Fig. 9).

The above-mentioned arrangement does not do away with the possible results of oil circuit-breaker explosions, but this danger is minimized by placing the circuit breakers in underground compartments opening on to the outside of the building, or at least not in communication with the rest of the plant, leaving in the "halle" only the tank cover and its bushings (see Fig. 10).

The best solution, however, and one which is finding increasing favour for substations, is the adoption of outdoor installations. In Italy there are many examples of these, ranging from 45 kV to 200 kV. A recent inquiry showed that there is undoubtedly an economy of installation (from 10 to 20 per cent) and greater operating safety. Only in mountainous districts do the heavy snowfalls and low temperatures necessitate the use of indoor plants.

Although a few substations are built of reinforced concrete [for instance, the Chivasso 70-kV substation, constructed in 1927 of spun reinforced concrete (see Fig. 12, Plate 2)], the majority of Italian outdoor installations are built of steel.

At the present time the greater number are of the vertical type, i.e. with busbars and disconnecting switches supported by structures, the various busbar systems being, in general, placed one above the other (see Figs. 8, 13, and 14, Plates 1 and 3). A few only have concrete roofs (e.g. Brugherio substation, Fig. 15, Plate 4). The horizontal type is now, however, becoming more common. In this type the busbars and disconnecting switches are placed practically on the ground. This, as a rule, leads to a certain economy and, moreover, this arrangement is compulsory for very high voltages.

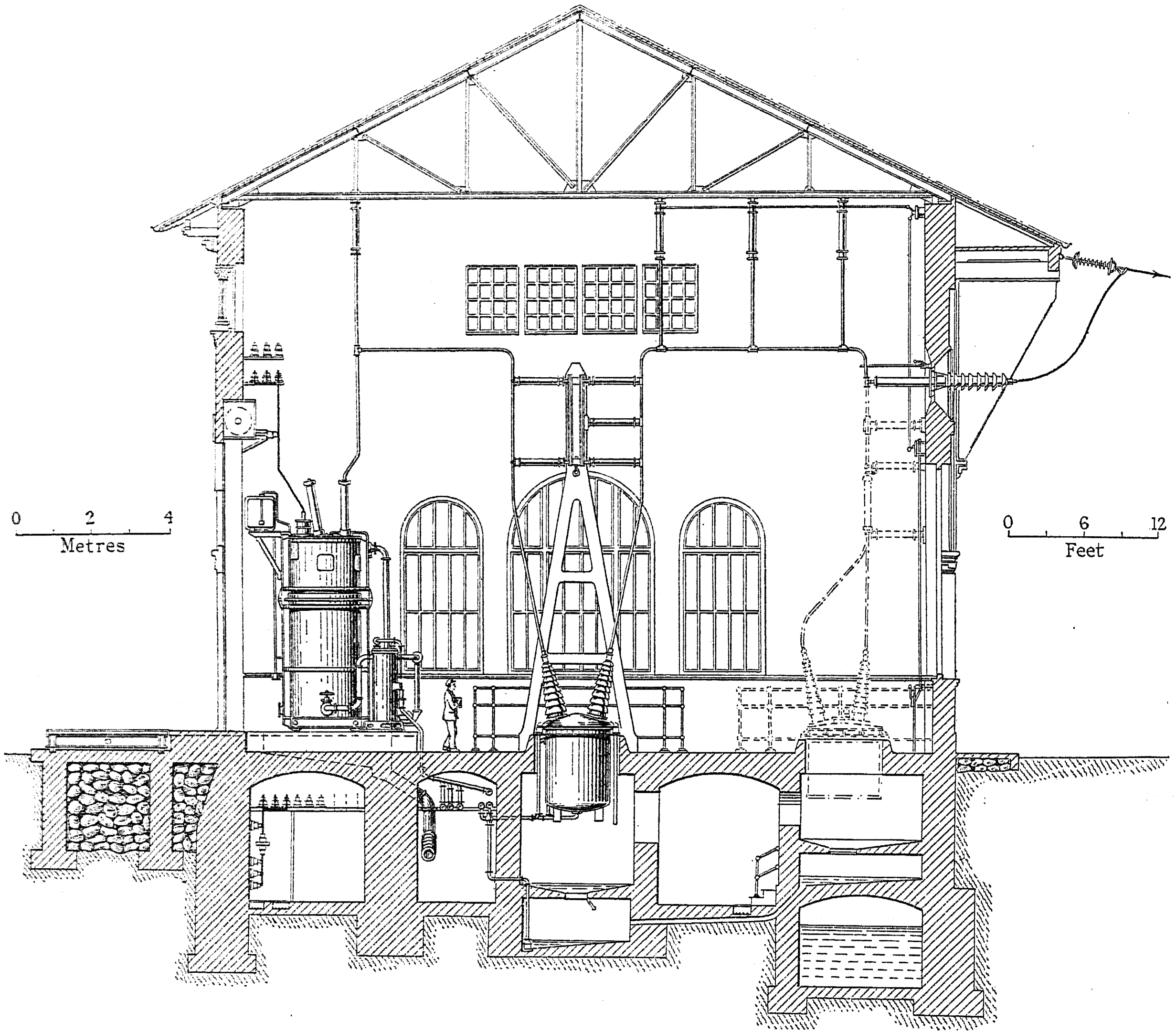

Fig. 10.—Part of 130-kV substation at Bordogna.

An interesting example of this system is illustrated in Figs. 16 and 17, which refer to the 240-kV section of the Cardano power station on the Isarco, already mentioned. Among the most important features of this plant are the wiring in 90-mm ($3\frac{1}{2}$ in.) steel pipes on 17-m (56 ft.) spans, and the rotating disconnecting switches of the expansion type, i.e. with double action, one for approaching the contacts and the other for closing them. An advantage of this type, in common with similar types largely used on Italian outdoor installations (after some rather haphazard trials had been made using ordinary disconnecting switches with blade and jaws), is that the contacts are rigidly locked without causing excessive bending stresses on the side insulators and twisting stresses on the central one. In addition, it can be operated even when ice and snow are on the contacts.

The ring busbar scheme has been discarded on the grounds of complication, and a simpler scheme has been evolved. Each line or machine main is connected to each busbar, usually through plain disconnecting switches, while in general there is only one oil circuit-breaker for each element. Provision is made for synchronizing the busbar systems and the lines (if necessary), and therefore economical synchronizing equipments are gradually becoming more popular. At Cislago, where the 200-kV line arrives, the charging current of the line circuit-breaker bushings, which are of the condenser type, is successfully employed for synchronizing, voltage-measurement, earth-fault detection, etc.

As already mentioned, in Italy there is a strong tendency towards discarding lightning arrestors, at least for high voltages. In a few 125-kV plants "Campos coils" (a combination of inductances and resistances) are used, but in the majority of the installations the protection against over-voltages relies upon the quality of the insulation; however, earth coils (particularly the 4-leg type, the fourth leg being inserted between the neutral point of the other three and the earth) with secondary windings for metering and synchronizing purposes, are coming into general use. These earth coils appear to be very efficient for eliminating static charges. Good results have been obtained, generally with earth-wires, which will be discussed later in the paper.

The adoption of solidly earthed neutrals on a few 125-kV systems, and on the 200-kV line (neutral earthed at the two ends), although not countenanced by the telephone authorities, who fear interference, was also quite successful; for instance, the 200-kV line which has been in continuous operation since January 1930 has not interfered in any way with telephone plants.

Simplicity is also the keynote of the auxiliary circuits; the complicated methods of over-current protection employed in other countries have not found much favour in Italy, where perhaps more attention is given to the selection of operating engineers and workmen.

Phenomena due to instability have been very rare, owing to the features of Italian transmission systems, the load on which, generally, is still far from reaching the limit. Therefore, the method of automatically lowering the generator voltage in the event of external faults is in fairly general use. This method is not advisable when the stability is poor, but it obviously lightens the work of the circuit breakers in the power stations, which have to open under load only when the fault occurs inside the machines; in this case the differential relays, especially those of the wattmeter type, which are employed on rather a large scale, come into operation before the voltage-lowering device begins to act.

Distance relays are also in use, but no definite data as to their operation are yet available.

Miniature switchboards are, also for reasons of simplicity, not very widely used, as their advantages appear to be counteracted by rather complicated wiring and equipment.

In Italy there are already a few examples of automatic power stations in very successful operation.

Overhead Lines.

It is impossible to give a detailed description of all the features of the Italian high-voltage lines; a few only of the fundamental principles adopted will be mentioned.

In general the towers are of the lattice-steel type, but reinforced-concrete poles, particularly those of the spun type, are coming into wide use.

The lattice-steel towers for voltages not exceeding 150 kV are generally of the narrow-base type with one foundation block (see Figs. 18 and 19), although on a few of the 125–150-kV lines the towers have broad bases (see Fig. 20, Plate 4).

For the mountainous section of the 200-kV line at Isarco a type of tower with a broad base (7·50 m × 7·50 m, i.e. 25 ft. × 25 ft.) was adopted, with conductors in a horizontal plane with 7·25-m (24 ft.) spacing (see Fig. 21, also Figs. 22 and 23, Plate 5).

Usually the steel members are riveted at the factory and the pole is shipped in sections 6 to 7 m (20–23 ft.) in length, to conform to the length of the railway trucks.

For lines running along mountainous routes, where transport is difficult, and for poles with broad bases, the members are shipped singly and bolted together on site (see Fig. 23, Plate 5).

The material used for transmission towers is generally steel with an ultimate tensile strength of 37–42 kg/mm^2 (52 500–60 000 lb. per sq. in.), a 20 per cent elongation, and a 7–9 kg/m per cm^2 (325–420 lb./ft. per square inch) resilience. Recent studies carried out on the vibration of the conductors have led to great importance being given to the resilience, especially in the case of mountain lines exposed to low temperatures, which augment their brittleness.

Fig. 24 (Plate 5) shows towers of the type in use in Sardinia (wooden poles mounted on concrete bases).

Some very important 125-kV lines have reinforced concrete poles (see Figs. 25 and 26, Plate 6) similar to those used on that part of the 200-kV Isarco line which runs over the plains, for which a type of structure with two legs for standard poles and four legs for special crossings (see Figs. 27 and 28, Plate 6) was adopted.

These spun reinforced-concrete poles are coming into great use on account of their price, which is generally lower than that of lattice-steel poles, the smaller amount of ground surface occupied, and the elimination of the expensive protective coating which is absolutely necessary for steel structures.

For steel poles galvanizing has not yet been adopted in Italy on a very large scale, since it is rather expensive. On some lines the galvanizing is limited to the top of the towers, the maintenance of which during operation is very costly

Mechanical Calculation.—Standard towers are generally calculated for a factor of safety of 3 based on "normal" loads, and the ultimate tensile stress on the buckling load by Tetmayer's and Eulero's formulæ for axial compression.

Under "abnormal" loads the factor of safety is reduced to about 2.

By "normal" loads is meant those under the worst conditions with all the conductors intact, and by "abnormal" loads those under the worst conditions when one or more conductors have broken (one for straight-line poles and more for angle poles).

The worst conditions are generally those due to one of the following causes:—

Vertical load due to snow on the conductors (from 1·2 to 1·7 kg/m, i.e. 0·80–1·15 lb./ft.) at a temperature of − 5° C. (23° F.) without wind.

Transverse load due to wind pressure on the conductors and poles (120 kg/m^2, or 25 lb./sq. ft.) for flat areas; reduction coefficient for cylindrical surfaces = 0·6; at the lowest temperature of the district (from − 25° C. to − 10° C., i.e. − 13° F. to + 14° F.) without snow.

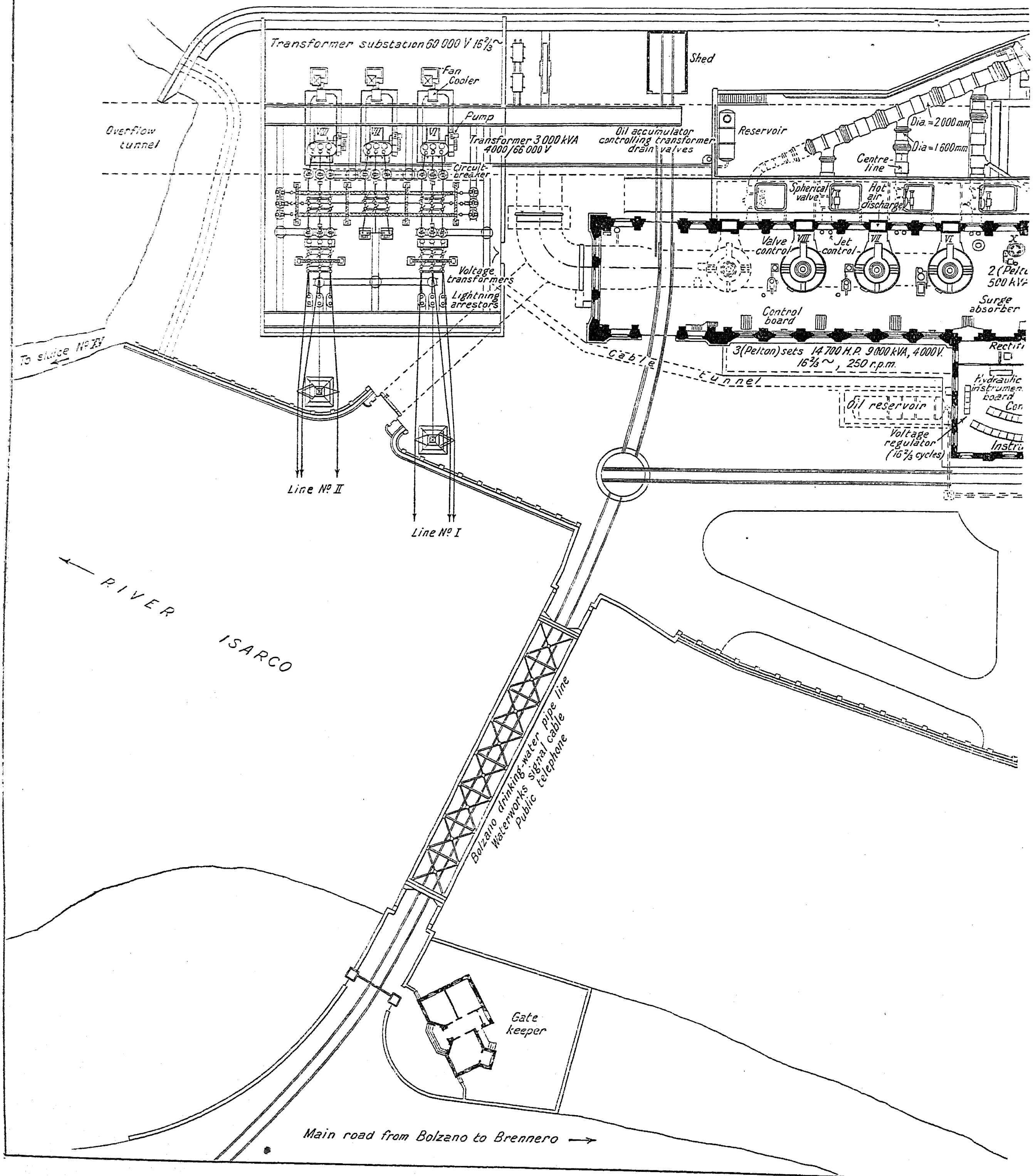

FIG. 16.—Cardano power station (240 kV).

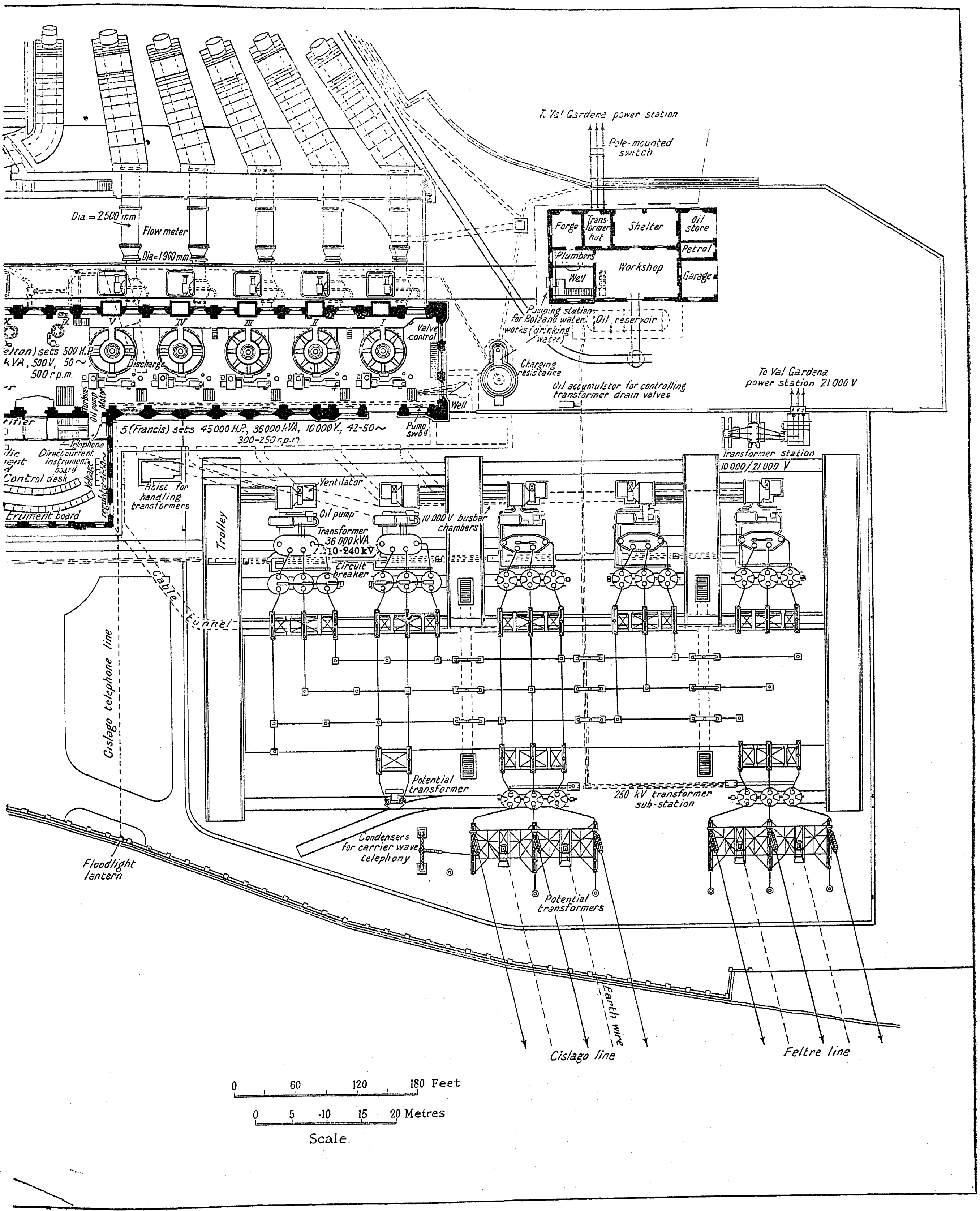

FIG. 16—(*continued*).

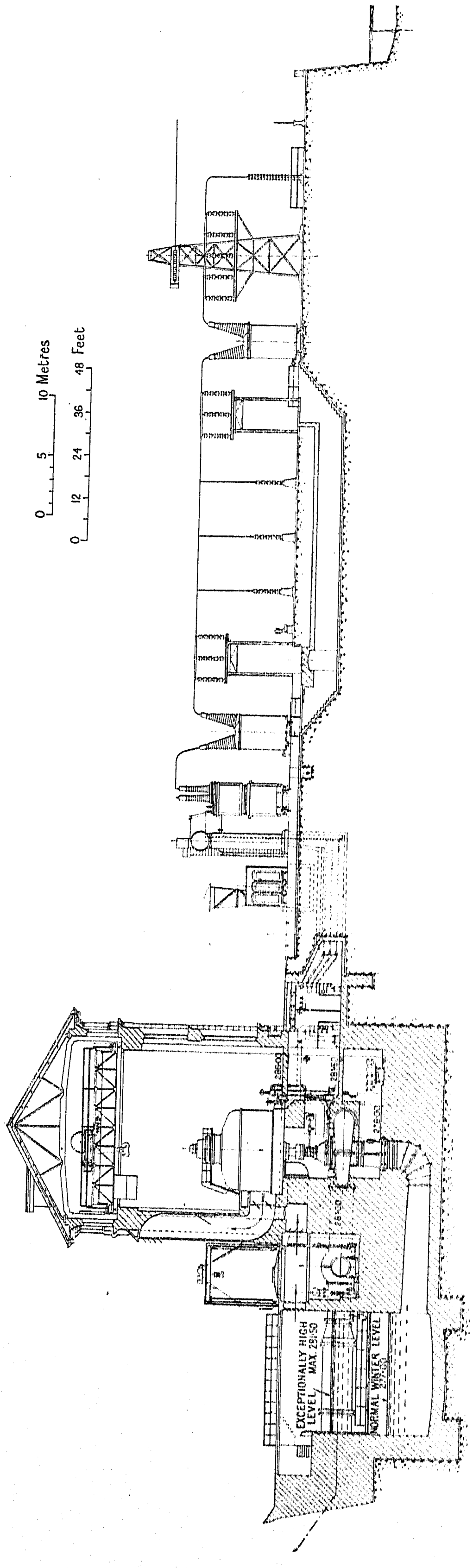

FIG. 17.—Cardano power station (240 kV).

As a rule the straight-line poles are calculated for angles of 3° and have a square base, in order to obtain a given stability also in the line direction.

The crossing of public services is governed by rules issued by the Railway and Telegraph Administrations and the Road Authority; these rules are for the most part very severe and there is on foot a strong movement for their revision, so as to bring them more into line with the broad views which Italian statesmen have always had as to the laws regarding electrical transmission.

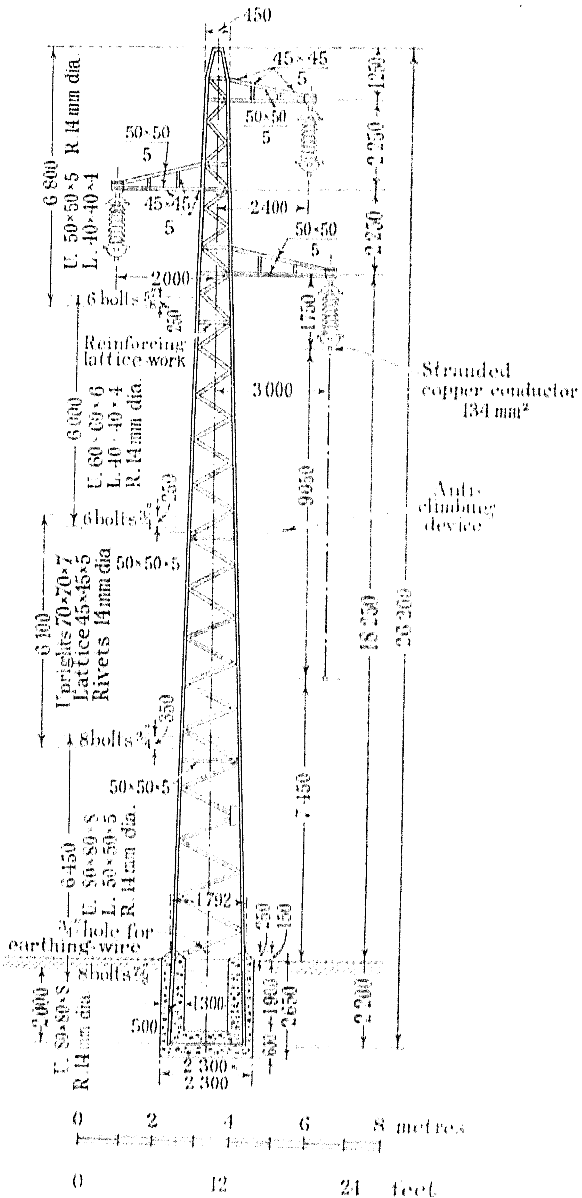

FIG. 18.—Poles used on the Maen–Covalou line (125 kV).

Foundations.—The foundations of poles are as a rule of the concrete block type; for straight-line poles, when the width permits, the central part of the block has a cavity filled in with earth. There are also special designs in reinforced concrete, etc., which might in some cases be more economic.

The towers of the Isarco line (see Fig. 21) have earth footings.

For the foundations of normal towers, the ground reaction is generally considered; but this is not admissible under the regulations governing crossings.

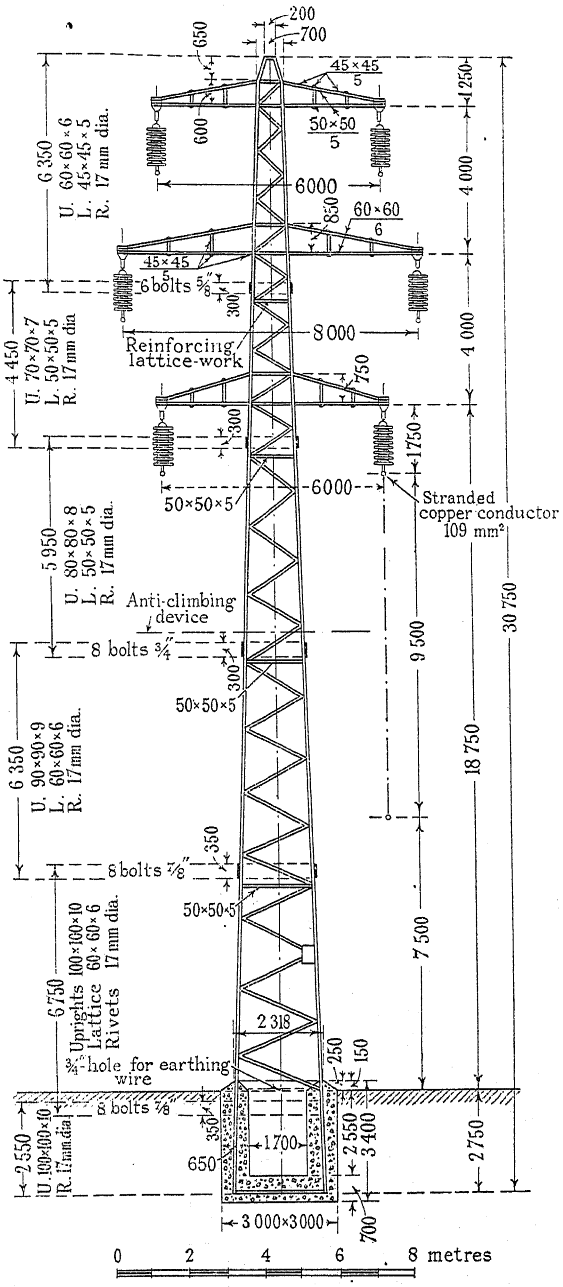

FIG. 19.—Poles used on the Covalou–Torino line (125 kV).

Spans.—There are no rules as regards the length of standard spans; but normally these vary from 180 to 250 m (600–800 ft.) for 60- and 125-kV lines. For mountainous sections of the 200-kV line the average span is 330 m (1 100 ft.).

The ground clearance at the middle of the span is normally 6 m (19·7 ft.), but for high voltages it is as a rule 7 m (23 ft.) or more. Special rules govern the sag at crossings.

Conductors.—The material most commonly used up to now has been copper, even for 150-kV lines, mostly stranded, solid conductors being used only for the smaller sections.

Lately steel-cored aluminium cables have come into use on the mountainous section of the 200-kV line and on a few 125-kV lines of recent construction. Conductors of " Aldrey " (an aluminium-magnesium alloy) are used for the 200-kV line in the plains and for several lower-voltage lines. Both these types of conductors are manufactured in Italy with Italian material, and are therefore approved by the Government.

Many engineers are considering the use of these light conductors on account of economy.

Among special conductors, hollow copper conductors (19·5 mm, i.e. $\frac{3}{4}$ in. diameter, 155 mm^2, i.e. 0·24 sq. in.) were employed with success on a 150-kV line (see Fig. 29).

As regards calculation for the stresses in parallel spans, the factor of safety allowed for copper, bronze, and steel is about 2, based upon the breaking stress of the cable, and the stress must not exceed 0·9 of the elastic limit. For " Aldrey " and steel-cored aluminium conductors, the factor of safety allowed is as a rule somewhat higher.

For calculating the sags, parabolic formulæ are generally used; for special spans and, lately, also for entire lines of any importance, exact methods employing catenary formulæ are used. An interesting practical application of these exact methods was made on the 200-kV line, on which a speed of calculation comparable with that obtained by the approximate methods was attained by the use of special diagrams.

For the calculation of composite conductors (steel-cored aluminium) the combined modulus of elasticity and combined coefficient of thermal expansion are generally employed, being obtained, by the well-known American methods, from the characteristics of each component metal.

On the 200-kV line the calculations also took into account the strength of the aluminium; of course, care was taken that under the different conditions of temperature and overload, the stress of the material did not exceed the safety limit, assuming a breaking load of 17 kg/mm^2 (24·150 lb./sq. in.).

The sizes of conductors have not yet been standardized; in general it may be said that on 60-kV lines copper cables of 60–90 mm^2 (0·10–0·14 sq. in.) are employed; on 120–150-kV lines copper or equivalent of 100–120 mm^2 (0·15–0·19 sq. in.); while for the 200-kV line the conductors are of 200 mm^2 (0·31 sq. in.) copper equivalent.

In making the choice, copper losses (the standard current density is about 1·5 amps./mm^2, i.e. 965 amps./sq. in.) and corona losses are taken into account.

As already mentioned, the question of the vibration of the conductors is now being considered, although up to the present there has been no trouble due to that cause; however, interesting types of " anti-vibration " clamps are now being tested.

Continuous Earth Wires.—Engineering opinion in Italy is at present divided on this question. A recent inquiry held by the U.N.F.I.E.L. showed that there is a steadily growing tendency for their use on lines at very high voltages because, with conductors high above the ground, for the same potential gradient the induced over-voltages are greater.

Continuous earth-wires are also employed on lines on which the earthing of the poles presents difficulties, as in the mountains.

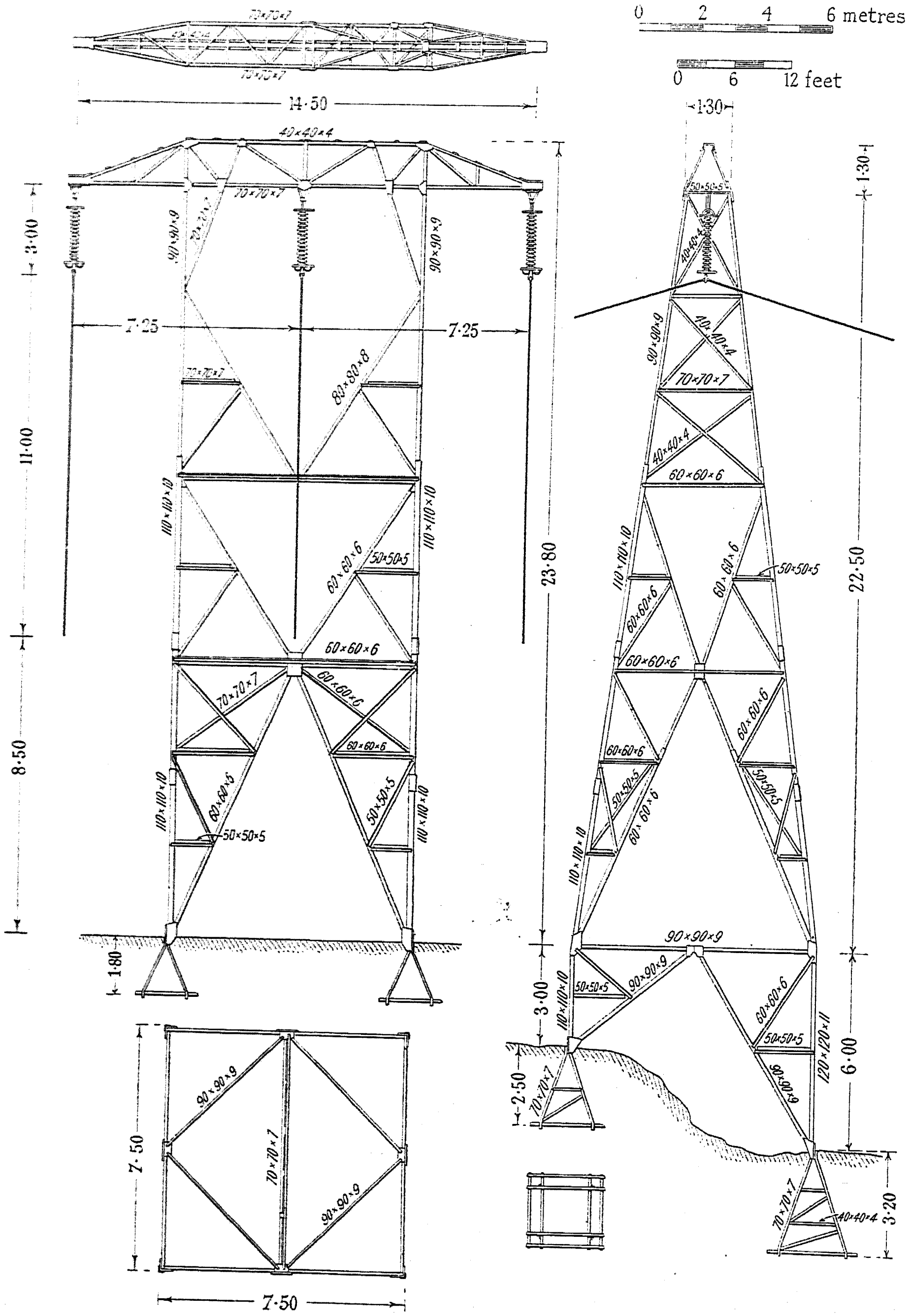

FIG. 21.—Poles used on Isarco line (200 kV).

With the exception of a few lines where two earth-wires are used, a single wire is generally employed, usually at the top of the pole.

Earth-wire Material.—On long spans, galvanized high-tensile steel (120–140 kg/mm², i.e. 170 000–200 000 lb./sq. in.) is usually used, while for shorter spans an average-grade steel (70–80 kg/mm², i.e. 100 000–113 500 lb./sq. in.) is employed. The section commonly used is 50 mm² (0·08 sq. in.).

Only one company, with the object of combining a high conductivity with adequate mechanical strength, uses a galvanized-steel cable with copper core.

Special attention is given to the clamping of the earth-wire to the pole (usually dead-ends to each pole are used) and to the joints between the various drum lengths, as the only trouble experienced up to now has been of a mechanical nature.

The increase in the cost of the line due to the adoption of continuous earth-wires is estimated to be under 5 per cent.

Insulators.—The pin type of insulator is no longer used on lines above 45 kV, and there is a growing tendency to discontinue its use even for this voltage.

Among the various kinds of suspension insulators the one chiefly used on the Italian lines is the cap-and-pin type, both cemented and not cemented. However, Jeffery Dewitt, Motor, Hewlett, and other types are also used.

For the suspension strings, elements 250 mm in diameter and 125 mm high (10 in. × 5 in.) are mostly used, having a tensile strength of about 4 500 kg (10 000 lb.).

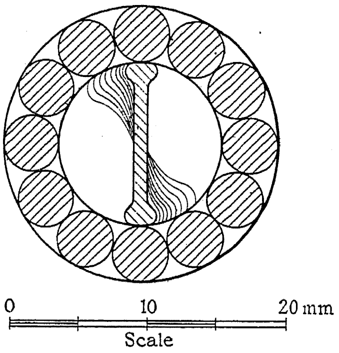

FIG. 29.—Tubular copper conductor.

Total sectional area = 155·2 mm².
Copper equivalent section = 153·35 mm².
Weight per metre = 1·445 kg.
Ultimate tensile strength = 6 271 kg.
Modulus of elasticity = 10 540 kg/mm².

For terminal poles the choice lies between multiple strings of standard insulators and single strings of special insulators. For instance, for the terminals of the first 200-kV line three strings of standard insulators (see Fig. 23, Plate 5) were employed. When it was double-circuited, two strings of stronger insulators (ultimate strength 7 000 kg, i.e. 15 500 lb.) were used, with a substantial resultant economy, due also to simplification of the fittings.

The tensile strength of the insulator used at terminals is 15 to 20 per cent higher than that of the conductor.

For the crossing of public services the regulations nearly always call for tension insulators, while for electric line crossings duplicate suspension strings are generally used.

The average numbers of units employed for the various voltages are given in Table 5.

Among the special features employed on some 125-kV Italian lines are devices for using at angles a single suspension string (see Fig. 30, Plate 6). The resultant advantages obtained due to the reduced stress in the strings are clear; the only objection to the device is its appearance.

There are two schools of thought as to the protection of insulators and conductors. A number of engineers think it better, principally for reasons of economy, not to install any protective device, while the exponents of protection have adopted arcing horns for voltages of 60 kV and rings (to the lower part of the string) for higher voltages. For the 200-kV line, rings were adopted for both the bottom and the top of the strings; the bottom rings are of 60-mm ($2\frac{3}{8}$ in.) iron pipe formed to a diameter of 600 mm ($23\frac{5}{8}$ in.); the top ones are of 15-mm ($\frac{5}{8}$ in.) iron wire formed to a ring of 600 mm ($23\frac{5}{8}$ in.) diameter. As already mentioned, this line has been in operation since January 1930 without any trouble being experienced.

Electrical Calculations.—A number of variations of the orthodox method of hyperbolic functions is used in Italy so as to facilitate the understanding of the phenomena and their calculation. The simple application of the common method with the development of hyperbolic functions in convergent series is now becoming general; thus any degree of approximation can be reached.

The graphical representation of the fundamental formulæ leads to a voltage and current diagram from which the powers also can be read on a suitable scale. By this means all the values that are necessary for design and operation are rapidly obtained.

TABLE 5.

Arrangement of strings	60 kV	125 kV	150 kV	200 kV
Plain suspension	5	9	10	15
Double suspension	6	10	11	16
Terminals (standard insulators)	6	10	11	17

The circle diagrams so widely used in America are also being studied; however, in the author's opinion they are not so easily and quickly understood and are also less representative of the phenomena than are polar diagrams (see Fig. 31).

E.H.T. Underground Cables.

In a paper presented by Mr. L. Emanueli at the Sectional Meeting of the World Power Conference held in 1929 in Tokyo, the following details of the most recent high-voltage cables installed in Italy are given:—

(*a*) The first is in Naples. It is 4 km (2·5 miles) long; it transmits 44 000 kW at 66 000 volts and comprises two circuits of single-core 120-mm² (0·19 sq. in.) cables arranged on the same plane in concrete conduits filled with sand.

A special feature of these cables is a double lead sheath, the object of which is to provide protection against electrolysis; the two sheaths are separated from one another by two sheets of impregnated paper and a layer of impregnated jute ribbon.

Another special feature of these cables is the split concentric conductor, the outer of which is formed by a single layer of copper wires separated from the inner part by a paper ribbon wound spirally. The idea is to form a central duct in the cable to allow the compound to expand freely when the cable heats up.

(*b*) Another cable, built on entirely different principles, is in operation in Milan. It is 1·2 km (0·75 mile) long and is composed of 3-phase 85-mm^2 (0·132 sq. in.) 70-kV cable of the oil-filled type. The cable has two lead sheaths, the outer of which forms a protection for the copper band wound spirally on the inner sheath, designed to assist the lead sheath to withstand the hydrostatic pressure due to the oil in the interior.

(*c*) The third cable is at Terni; it is 350 m (1 115 ft.) long and is composed of 3 single-core 132-kV cables of the oil-filled type with a section of 300 mm^2 (0·465 sq. in.) and a thickness of dielectric of 18 mm ($\frac{3}{4}$ in.). This cable is similar to those used in New York and Chicago,* the only difference being in the central duct, which has a diameter of 12 mm ($\frac{1}{2}$ in.) instead of 18 mm ($\frac{3}{4}$ in.).

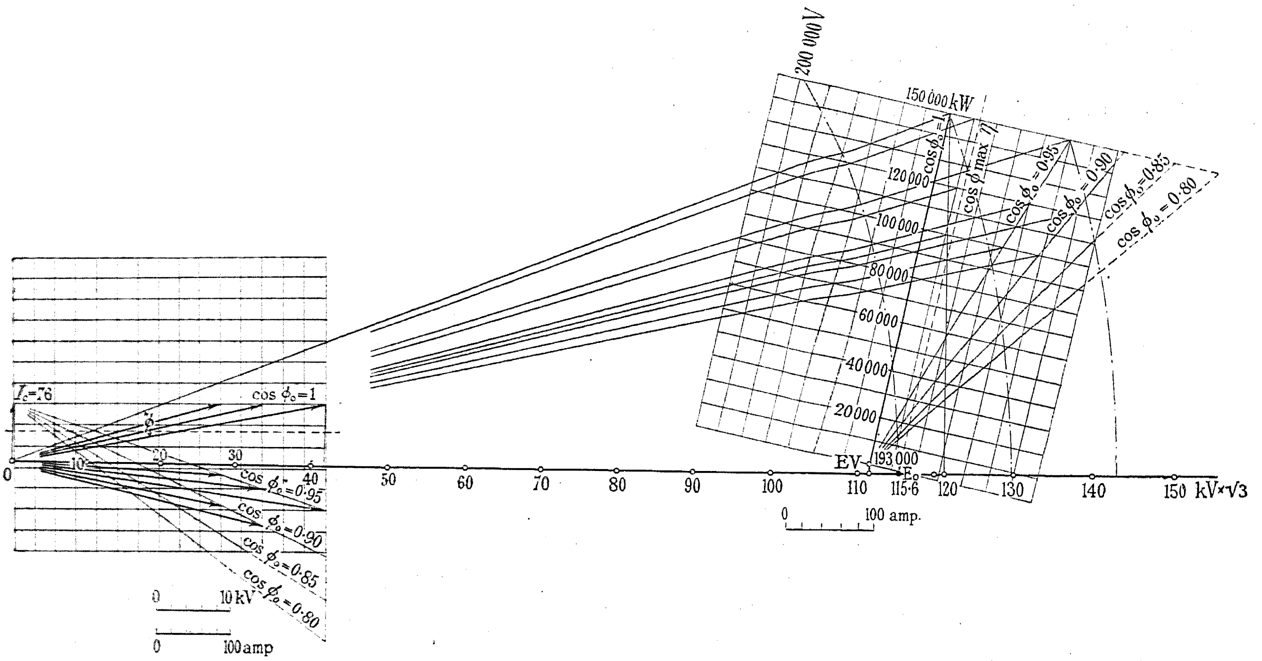

FIG. 31.—Diagram used in the electrical calculation of the Isarco line.

Since the publication of Mr. Emanueli's paper another line has been erected in Genoa, having 7 km (4·4 miles) of single-core cable at 110 kV. It is similar to that used at Terni and described above, but with a thickness of dielectric of 12 mm ($\frac{1}{2}$ in.).

For further details the reader is referred to Mr. Emanueli's paper.

Cables for 200 kV will soon be undergoing trials at the Cislago substation.

Operation.

As a rule, each of the large electric systems is controlled by a central plant manager. Only a few companies have a local manager for each of the more important generation and transmission groups forming its system. The "load dispatcher" idea, as adopted on American plants, has long been in operation in Italy, since the executive members, under the direct orders of the managers, are in effect load dispatchers. As in America, they have at their disposal complete plans of all the power stations and substations, and in accordance with the instructions of their manager they direct the operation of the plants and the load-dispatching, etc. Their duty is an onerous one, because in Italy the various power stations are separated by great distances. This difficulty has been partly overcome by the use of private telephone lines belonging to the company, run as a rule on separate poles. High-frequency telephone carrier systems are now coming into general use.

The foreman of each of the power stations or substations, although he is completely responsible for his own work, carries out only the service operations ordered by the load dispatcher.

The system originally adopted for maintenance of the lines was to have linesmen posted along the line at a distance of 15–20 km (9–13 miles) from each other. Each of these men periodically surveyed his length of line. At the present time the plan often adopted is to concentrate a number of linesmen at the main substation where they can normally be working and from whence they can travel by lorry to perform the necessary survey or repairs.

As regards the general principles underlying the operation of the systems, there may be mentioned the present trend towards the limitation of parallel operations in order to avoid serious consequences due to breakdowns. The individual services of a zone are usually arranged so as to allow, in emergency, synchronizing and load transfers to be made from one section to another. This plan is at present facilitated by the fact that the available plant capacity exceeds the demand. In the future, when the demand increases, the question will be reviewed because general parallel operation would then allow of a fuller exploitation of the available water and plant. In conclusion, it should be mentioned that increasing care has been given to the continuity and regularity of the supply during the last few years, with successful results from every point of view.

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* *Transactions of the American I.E.E.*, 1928, vol. 47, p. 186.

ACKNOWLEDGMENTS.

The author desires to thank Mr. C. E. Maguire for looking through the proofs of the paper, and Mr. L. B. Firnberg for his assistance in translating the wording on some of the drawings.

DISCUSSION BEFORE THE INSTITUTION, 17TH DECEMBER, 1931.

Mr. Roger T. Smith: The British "grid" is a high-voltage interconnection system between power stations belonging to undertakers, there being comparatively few low-voltage interconnections between the latter. All distribution is in the undertaker's hands. The Italian system is a true transmission system from power stations to step-down distributing centres. Interconnection as between districts or groups, and as between power stations in a group, is comparatively rare except where thermal stations are connected to hydraulic stations, or where hydraulic stations with different periods of maximum and minimum water-flow are interlinked. The British grid was laid down by Parliament as one comprehensive scheme, any change in it during progress being difficult. The capital for the scheme is raised by making the interest on it a first charge on the undertakers' revenue. The Board buys electricity from the undertakers and sells it back at a price which will cover expenses. The Italian scheme has grown naturally under private enterprise, with no State guarantee for interest on capital. All arrangements are by agreement. Wayleaves are obtained under the law of Boselli (now 40 years old) providing for compulsory wayleaves with compensation and with the law-courts as a last resort. In Italy power-station sites are fixed by the position of water power, and transmission routes are limited; hence the necessity for compulsory wayleaves. In Great Britain, so far as thermal stations are concerned, this is not the case. Figs. 1, 2, and 3, show the need for interconnection between the Alpine and Apennine power stations, and this has been carried out. It is interesting to note that considerations of safety make Italian engineers afraid of interconnecting groups, and that they do not favour parallel running. Also, they have deliberately decided against standardizing the different frequencies in various districts (see Fig. 5), on the ground that the advantage to be derived from such a course is not worth the expenditure it would entail. The British grid system of power-station interconnection has a high-voltage (above 100 kV) route length of 2 764 miles, as against Italy's transmission and interconnection system above 100 kV of 2 260 miles. In Italy the length of lines worked at less than 100 kV is between 4 and 5 times the route length of the high-voltage lines. The Italian route length of lines below 100 kV is more than 10 times ours, exclusive of the power lines belonging to power companies. This is due, of course, to the physical features of the country and the disadvantages of having to transmit from places where water power happens to be available, as well as to differences in the type of system adopted. It is interesting to note that the quantities of electricity generated annually in the two countries are very nearly the same for the year ended 31st December, 1930; the figures being 11 000 million units for Italy and 12 333 million units for Great Britain. The Italian figures include an estimate for private generating plant, while the British figures include some selected private plants. Both take into consideration the power generated for railways and tramways. Recent developments in rectifiers, either rotary or mercury-arc (especially the latter), including the controlled-grid mercury-arc rectifier which turns direct current into alternating current, will, when available commercially, greatly increase the potential capacity of the transmission lines by substituting d.c. for a.c. transmission, and will make frequency standardization unnecessary. Incidentally, the reversibility of the mercury rectifier—now accomplished in small plants—opens out possibilities of greatly reducing the cost of railway electrification. On page 400 the author refers to the use of synchronous and asynchronous motors for power-factor and voltage control. I should be glad to know whether in Italy harmonics have caused any serious trouble. Is provision made for any synchronous machinery which may be needed for supplying the magnetizing current of the step-up and step-down transformers on the system, as well as for the regulation of voltage and power factor? It would be interesting to point out some of the likenesses and differences between the design of the Italian overhead high-voltage transmission system and that of the British grid, and I hope that other speakers will do this. In conclusion, I would point out that in his Kelvin Lecture for 1924* the late Guido Semenza applied Kelvin's law of minimum cost of conductors to the design of tower lines, and showed that under certain conditions the small-base steel tower was the most economical. That conclusion seems to have been adopted in the earlier Italian lines (Figs. 18 and 19) and on lines up to 150 kV (Figs. 20 and 30). It is evidently untrue for 200 000-volt lines, judging by Figs. 22 and 23.

Mr. J. M. Kennedy: With regard to the frequency chart shown in Fig. 5, is there not a large 16-cycle area for railway electrification in Northern Italy? On page 410 the author states that the interconnection of large consumers "is at present facilitated by the fact that the available plant capacity exceeds the demand." Great Britain's strongest argument for her grid interconnection system is that it will reduce the amount of spare plant necessary, and it would therefore be interesting to know how it is that the big Italian transmission system has grown up in spite of the fact that the spare-plant capacity was not being reduced thereby. Although the author does not say much about it, his latest designs (Fig. 17) of outdoor substation gear are more or less similar to those adopted in British low-type substations with reinforced-concrete gantrys, a construction of which I entirely approve. When I was in Italy last summer I was very interested in the poles for the 200 000-volt line (Fig. 27). The author refers to the provision made for draining away the oil from circuit breakers and transformers, and in this connection it would be interesting to know whether any provision is made for extinguishing fires in the underground passages. What is meant by the "ring busbar scheme" mentioned on page 402 as having been discarded? After trying various arrangements of switches and busbars I have formed a favourable opinion of what I call a "ring or mesh busbar scheme," which seems to have great possibilities from the economic point of view. (Mr. Kennedy illustrated his remarks by means of a diagram.)

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* *Journal I.E.E.*, 1924, vol. 62, p. 882.

Mr. W. P. Digby: It is a matter of some significance that the whole of the equipment in the Isarco power station and of all stations recently constructed or now under construction, was made in Italy. It is an interesting example of what can be done in a country to develop new industries behind a tariff wall. It is even more interesting to go back 20 years to the electrical exhibition at Turin in the autumn of 1911, and to recall the statement, made by an Englishman in the columns of one of our engineering papers, that Italy was on the verge of industrial developments which would be comparable in their effect with the artistic Renaissance of the Middle Ages. There have been developments not only in electrical but also in mechanical engineering; the latter have culminated in the launching this year of two 45 000-ton liners and in the construction of the Pelton wheels and reaction turbines for the power houses described in the paper. The valves and pipe lines associated with these are also of Italian make, and one can find in Italy more types of pipe lines for hydroelectric works than there are in the whole of the British Empire. The author's flow diagrams (Figs. 1, 2, and 3) are of great interest, and in this connection it is to be regretted that many of the long, narrow valleys of Northern Italy do not lend themselves to the construction of large reservoirs which would help the water-power stations over periods of drought. In regard to Fig. 5, what are the maximum sizes of frequency-changers employed? I hope that the author will give, either in his reply to the discussion or in a future paper, some indication of the capital outlay per kW installed in the power houses. In view of the popular misapprehension in this country that water power costs nothing, it would be interesting to have information as to the typical Italian rates for bulk purchases of electrical energy for industrial factories, for metallurgical or chemical factories, for municipalities, and for the State railways. In Italy, as in this country, the increase in size of transformers has led to difficulties of transport, and in this connection some units which I have recently seen with cast-iron cases and machined joints seem to provide a satisfactory solution of the problems associated with transformers having radiator cooling with the radiators secured to the tank by flanged joints. The author's remarks on the difficulties of transformer cooling I can well appreciate, but I think that the tubular cooler might be more extensively used in Italy, because in mountain districts the water is exceptionally pure and the corrosion risks therefore very small. I grant that in other types of substations the solution of the transformer cooling problem may have to take a different form. In regard to steel towers for transmission lines in Italy, the general tendency is to use lighter sections than are employed in this country. For instance, referring to Fig. 21, the upper members of the poles shown are 40 mm by 40 mm by only 4 mm thickness. The last figure is very much lower than would be adopted in this country, and bigger sections are, I think, desirable. Galvanizing is rare on the Italian overhead lines, and it must be admitted that except in the neighbourhood of the sea there is little need for it in Northern Italy. On page 403 the author states:—"On some lines the galvanizing is limited to the top of the towers, the maintenance of which during operation is very costly." If one galvanizes the upper portion of the tower and paints the lower portion, the question arises:—What will happen when that initially impermeable membrane which is called paint becomes permeable? The junction between the galvanized and the ungalvanized steel members should, I think, be regarded with great suspicion.

Mr. A. Dalla Verde (*in reply*): Mr. Roger Smith's remarks show a deep knowledge of the Italian electrical problem. His idea that Italian engineers are afraid to interconnect groups makes me fear that I did not express myself with sufficient clearness in the paper. As a matter of fact, there is no hesitation in introducing such interconnection and, as is indicated by Figs. 4 and 6, it has been largely adopted in Italy. What, for reasons of safety, is not much favoured is the parallel running of large systems Many Italian companies interconnect all their power stations during the winter season, when storms are rare and water is scarce, i.e. when the necessity arises of utilizing all the hydraulic resources and there is less likelihood of troubles. In the summer, however, when storms are frequent and the water-level high, the different districts are made independent of each other and are fed by different stations. As regards troubles due to harmonics, the only ones worth mentioning of which I know are those which took place some 15 years ago in the Valdossola, on telephone and telegraph lines, owing to the presence of electric lines fed by auto-transformers at 25–45 kV having earthed neutrals. These troubles were eliminated by adopting transformers having separate delta windings. As mentioned in the paper, recent experience of 125- and 200-kV lines with earthed neutrals has been satisfactory. The choice of steel towers for the Isarco line (see Figs. 22 and 23) was largely determined by the route of the line, most of it being in high mountain regions, where it was very difficult to supply the materials needed for the concrete block foundations and therefore essential to use the broad-base type. Moreover, comparison of the various types of towers showed that the one adopted for this particular case was the most economical.

In reply to Mr. Kennedy's first comment, a 16-cycle area is not shown in Fig. 5 for the reason that this frequency is used solely for traction and is not related to distribution areas. In connection with his second observation, at present the available plant capacity exceeds the demand only on account of the economic depression, whilst interconnection has of course resulted in a reduction in the amount of spare plant required. As regards oil set on fire owing to troubles with transformers or circuit breakers, we usually arrange for the oil to drain rapidly away into underground tanks, where the fire is extinguished for lack of oxygen. In addition, modern stations are usually equipped with fire extinguishers of the CO_2 or foamite type.

I thank Mr. Digby for his kind remarks. As far as I am aware, the largest frequency-changer is the 9 200-kVA 42/16·6-cycle one installed at Mezzocorona, near Trento, of a special type, which is illustrated by Mr. Santuari in *L'Energia Elettrica* (March–May, 1929). In reply to Mr. Digby's request for particulars of the cost of water power, the capital outlay is about 2 to 2.50 lire per unit sold yearly, approximately half of this being the cost of generation and the other half transmission and distribution. I shall publish at a later date particulars of the tariffs adopted in Italy. The statement that some members of the Isarco line towers are of light section is correct. It should be noted, however, that they were employed only as secondary members. Moreover, in order to confirm the calculations, some towers were tested to breakdown in the factory, with satisfactory results (see my Report at the Conférence des Grands Réseaux Électriques, 1931). The line was erected in December 1929 and, so far, no troubles have occurred. Maximum economy in the dimensions of the members of the towers is essential in Italy owing to the high cost of iron, but safety is always the first consideration. As regards the junctions between galvanized and ungalvanized steel, no troubles have so far come to my knowledge. I did not mention reservoirs (which are extensively employed in Italy), because they did not come within the scope of the paper.

NORTH-EASTERN CENTRE, AT NEWCASTLE, 14TH DECEMBER, 1931.

Mr. D. M. Buist: The paper enables a comparison to be made between modern practice in Italy and in Great Britain. On page 394 the author makes the interesting statement that "thanks to the foresight of the statesmen, Italian industrial concerns do not find insuperable obstacles in the way of their schemes." This is the keynote of the comparison between Italy and Great Britain to-day, and it is not too much to say that 30 years ago the Italian Government passed the equivalent of the British Government's 1926 Act. The result of Boselli's Bill was that the "splendid isolation" referred to by the author, and which was also encountered in Great Britain, did not prevent development and necessitate State intervention as in this country. Boselli's Bill contains many provisions which could with advantage have been included in our Act of 1926, particularly the clauses regarding wayleaves, crossings, etc. These matters are much more vital than engineers in general seem to realize, because they represent an appreciable proportion of the capital costs of transmission. I am interested to note that in Italy, as in this country, there is no compulsion regarding the crossing of gardens and buildings, and also that the Italian wayleave terms are practically the same as the British. The author refers (page 396) to the multiplicity of lines between common points; it appears to me that the reluctance of the Italian engineers to interconnection a large scale arises more from this unusual multiplicity of lines and from the absence both of frequency standardization and of a co-ordinating body, than from any fear of more disastrous results from breakdowns. Surely, with frequencies of 42, 46, and 50, standardization difficulties should not be insuperable. Italy should take a lead from France and Britain in this matter and remember that a bold policy is the best in the end, because the longer the delay the greater is the cost and the more difficult the problem. It is interesting to note that Italy has the equivalent of the British grid, except that the system is operated by eight separate groups on the mainland. It appears to me that Italian engineers have a splendid opportunity of achieving great economies by a co-ordinated policy of interconnection, selection of efficient generating stations, reduction of transformation and transmission losses, and elimination both of frequency-changers and of dual-frequency plant. All this could be achieved with little extra capital expenditure on transmission, but would, of course, entail expenditure on changing-over. The author admits that interconnection would allow of fuller exploitation of both generating and transmission plant, and I am surprised that Italian engineers, who are usually in the van of progress, have not yet tackled this problem. Tables 3 and 4 show that fully one-third of the Italian generating stations are thermal, and although they contain over 16 per cent (nearly 800 000 kW) of the total installed plant, their output is only 3 per cent of the total energy production. A central co-ordinating body would eliminate a large number of the smaller and water-power stations, would select such large thermal stations as Naples, Rome, Genoa, and Venice, for peak loads and drought periods, would greatly improve the present poor installed-plant load-factor (4½ per cent) of thermal stations, and would enable full advantage to be taken of the dovetailing of the Alpine and Apennine flows. To my mind the large proportion of thermal stations and their low plant factors go to prove that full advantage is not taken of the unique natural dovetailing of the hydro-electric plants, due presumably to the separate grouping system. On page 399 the author hints that he regrets the "loss of variety" resulting from standardization of manufacture. From a technical point of view, however, loss of variety need not necessarily mean loss of the artistic point of view. The hydro-electric plants are more interesting than the thermal plants, which latter have no outstanding features, probably because they are of secondary consideration in Italy. Regarding the high-voltage substation layouts, I am surprised to learn that outdoor installations are only now being adopted on a large scale in Italy. All such substations in this country are of the outdoor type. In America the outdoor policy is even being applied to power stations, but on the North-East Coast we are building a power station of an intermediate type, viz. glass-covered. I am struck by the statement on page 403 that Italy prefers to spend more money on staff than on overload protection. I agree with this policy to a certain extent, because I have too often seen automatic apparatus ruined by lack of skilled attention. On the other hand, even highly skilled operating engineers cannot be expected to discriminate as quickly and as accurately as automatic protective devices; the Italian policy in this connection recalls the days when "volt-boys" were retained by undertakers who viewed the innovation of automatic voltage regulation with suspicion. I am particularly interested in the description of the overhead lines, and to learn that reinforced-concrete poles are employed on the 200 000-volt Isarco line. With this exception, the line construction is on the whole roughly similar to British practice. If ever I visit Italy, I should like to see:—(*a*) the Cardano power station; (*b*) the Isarco 200 000-volt line and substations; and (*c*) the oil-filled cables. Regarding (*c*), I am surprised to learn that Italy has only ¾ mile of 3-core oil-filled 70 000-volt cable. In the North-East Coast area alone, the Central Electricity Board has laid 12 miles of 3-core, and 33 miles of single-core, 66 000-volt oil-filled cable. In conclusion, I should like to ask the following questions:—

(1) Is the Sicilian network connected by submarine cables across the Straits of Messina to the network on the mainland?

(2) How does the author account for the low installed-plant load-factor of 4·5 per cent of the thermal stations?

(3) Why should Italy import 164 000 000 units per annum (fully 6 per cent of the total consumption), especially considering that there is no shortage of generating plant?

(4) Referring to page 399, has Italy considered distributing at 66 000 volts? Does the author consider that this voltage would be economical, or is it his opinion that Italy's present maximum distribution voltage of 45 000 volts is the highest at which tapping of the lines is economical?

(5) Referring to page 403, if interconnection is nationally adopted will the Italian engineers retain their present method of automatically lowering the generator voltage on faults?

(6) By how much per cent is the reinforced-concrete pole cheaper than the equivalent steel pole?

(7) Why did the Italian engineers adopt the design shown in Fig. 21 for the 200 000-volt tower, in preference to the more orthodox design?

(8) How long has the 132 000-volt single-core oil-filled cable at Terni been in commission, and is it satisfactory?

Mr. F. C. Winfield: I am struck by the very strong similarity between Italian and English practice. In this country the 3-phase transformer now definitely holds the field. Air-blast cooling is also very well established, and above 10 000 kVA capacity it is likely to be generally used except where a reliable water supply can easily be obtained. For example, it is unlikely that air-blast transformers will be used in power-station work, on account of the greater economy of the water-cooled type under these conditions, but the opposite holds for general substation work. For sizes below 10 000 kVA self-cooled units are usually employed, and it is probable that this practice will be continued. The author makes no reference to the use of on-load ratio-changing devices in connection with transformers. In this country it is likely that on-load tap-changing will be employed on most large transformers in future, as the advantages of having some means of voltage adjustment at principal points on a system are widely realized. In this connection, the author makes only a passing reference to the methods employed for controlling the voltage and power factor of the various lines in the Italian interconnected system. I should be glad if he would amplify his remarks on this point. For the most efficient control of a large interconnected system complete freedom on the part of the control engineer is necessary, and this depends very much on the agreements between the various companies which are interlinked and on the methods of charging for power. Unless these are very carefully worked out grave difficulties are likely to occur, not because of the lack of plant or of means of control, but because of financial objections on the part of the various individual groups to being operated in the manner which the control engineer desires. An outline of the usual form of agreement between groups in Italy would be of great interest. It would appear from the paper that actual running interconnection, i.e. operation of parallel lines, is not employed to any great extent in Italy, the quantity of copper available being at present sufficiently in excess of that required to deal with the load to make it convenient and reasonable not to indulge in a great deal of interconnection. When, however, these conditions change (and the author suggests that they will) this matter is likely to become much more prominent. Regarding substation lay-out, the author criticizes the scheme shown in Fig. 9 in that it offers no protection against the complete failure of a circuit breaker, apart from the facilities which it provides for oil drainage. I would draw attention to the disadvantage that five handling sidings are employed, resulting in rather expensive construction of the foundation block. Otherwise this lay-out is very simple and straightforward, and it conforms in general with present-day views in this country. British engineers are now paying less attention to handling than in the past, as they realize that major handling is a rather infrequent occurrence and that therefore very elaborate arrangements for easy handling are probably not justifiable. The arrangement shown in Fig. 10 is interesting because of the very elaborate below-ground building work. It is possible, of course, that the particular site conditions suited this form of construction; but the general tendency in this country is to build upwards rather than downwards, as usually below-ground construction is considerably more expensive than above-ground construction. Fig. 10 gives no indication of how the circuit breakers are handled for removal, although it would appear that the tanks can be lowered. Presumably special lifting tackle has to be installed for general removal. The horizontal type of outdoor substation is now used exclusively for 132-kV work in this country where site restrictions do not exist. The high type of substation is only used where the site conditions are cramped. I am interested to note that in the 240-kV substation at Cardano 56-ft. spans of 90-mm steel pipes are used for busbar construction. In the 132-kV substations in this country 32-ft. spans of 76-mm steel tubing were first considered for busbars, but experience showed that these were insufficiently rigid and that when used outdoors they would be liable to considerable vibration, which might result in failure of the cement joints in the post insulators supporting them. The span length was therefore reduced considerably. I should be interested to know whether any difficulties have occurred with the 56-ft. spans referred to by the author. Could he give some further particulars of the expansion-type switches referred to on page 402? It is noteworthy that duplicate busbars are not much used for the Italian high-voltage substations. The single-busbar arrangement, of course, very much simplifies the lay-out. Generally, however, the Italian method of running seems to resemble the German method rather more than the British, in that interconnection and its inherent difficulties are avoided as far as possible. The 132-kV system in this country is solidly earthed at every substation through the connected transformers, so that we do not anticipate any maintained static charges. No difficulty has as yet occurred with telephone interference, but it is clear that to prevent this occurring it will in certain cases be necessary to limit the earth-fault current. The author states that phenomena due to instability have been very rare; this is probably the result of the running conditions which they adopt.

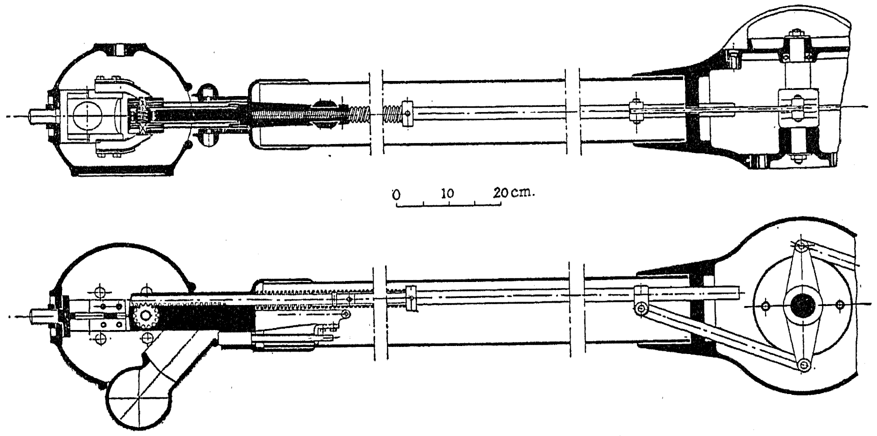

Fig. A.—Expansion-type 220-kV switch.

Mr. J. A. Harle: I propose to confine my comments to those parts of the paper which deal with equipment. I note (page 402) that the charging current of the line circuit-breaker bushings is used for purposes of synchronizing, metering, and arcing-ground detection; this practice appears to be a definite economy, and it is in line with that favoured in other countries. I should be glad if the author would indicate whether it has proved effective in practice. I assume that he intends the term "metering" to refer here to indicating meters, as it is doubtful whether any of the schemes developed for this purpose are of sufficient accuracy for energy measurement. I note from page 403 that lightning arrestors are being discarded, thus bringing Italy into line with this and other countries so far as lightning protection is concerned. I should be glad of some information as to the behaviour in practice of the Campos type of protection, as, while the various schemes put forward are extremely ingenious, they would appear to be only of a palliative nature. They eliminate a small percentage of the surge wave only, unless their dimensions are increased out of all proportion.

Mr. A. Dalla Verde (*in reply*): Mr. Buist's remarks about the reluctance of Italian engineers to adopt interconnection on a large scale do not exactly reflect my views. At the present time Italian engineers willingly approve interconnection, but, on the other hand, they do not favour parallel running (see my reply to Mr. Roger Smith on page 412). As regards thermal stations and their low load factors, I should like to draw attention to the fact that the most modern and important stations were built as a result of the lesson which we learned during the winter 1921–1922. We had at that time such unusual and extraordinarily low water-levels that it was necessary to limit the power supplied to factories. In Italy, therefore, steam stations have the special purpose of serving as a stand-by in case of exceptionally low water-levels, and during recent years it has rarely been necessary to make use of them. Outdoor substations have now been fully developed in Italy, and the first ones were built as long ago as 1920. As regards overload protection, whilst the lines and the plants will gradually become more and more complex, automatic protection will gradually be extended in Italy, where, perhaps, there is still a little scepticism owing to the fact that the first protective installations were rather unsuccessful. The following are specific replies to Mr. Buist's questions:—

(1) The Sicilian network is not yet connected to the Continental lines.

(2) The thermal stations' low load-factor is explained by what I have said above.

(3) The electric power imported from foreign countries is generated by a company directly controlled by an Italian electric group and is also due to some special purchase agreements made many years ago.

(4) 66 kV is generally used for large transmissions, but some important customers are fed directly at that voltage.

(5) My own opinion is that a large system of intercon-

nection will necessitate a modification of the present practice of lowering the generator voltage on the occasion of a fault.

(6) It is impossible to state definitely how much cheaper are reinforced-concrete poles than steel towers. The average saving, including all expenses, is from 10 to 20 per cent.

(7) The type of steel pole used for the 220 000-V Isarco line was finally adopted after lengthy investigations. It was considered to be the most economical type for the special conditions where lines are run in the mountains (see my reply to Mr. Roger Smith, *loc. cit.*). Besides, I believe that the design adopted for that particular voltage is really the most orthodox. In America it is used exclusively; whilst in France and in Germany a different design has been adopted, but for lines mostly in level country.

(8) The single-phase oil-filled cable for 132 kV was installed at Terni about three years ago and it has always proved satisfactory.

Mr. Winfield wishes to obtain some further information about the methods of controlling voltage and power factor in interconnected systems. As far as I know, there has been no serious difficulty in Italy. The synchronous condensers which every system employs are generally sufficient to satisfy every single demand. The spirit of technical *camaraderie* among the various groups is much developed, even when they belong to different financial companies, and an arrangement is always possible. The real difficulties are to be found in the regulation of the load; when the systems are rigidly tied together the control of the load to be exchanged is very difficult and sometimes even impossible. One method, now widely used, for overcoming these difficulties is to make agreements to exchange power on the kWh basis, allowing a certain freedom as regards kilowatts. In the arrangement illustrated in Fig. 10, the cover and the movable gear of the circuit breakers are lifted by means of a tackle suspended from the hook which may be seen above the breaker. These parts are then carried to the workshop by means of a special roller. The tank cannot be lowered. The busbars installed on the 240-kV line at Cardano have not presented any trouble since 1929, notwithstanding a span 56 ft. in length. It must, however, be noted that the busbars are connected to the insulators by means of very long and strong clamps. One of the switches of the expansion type used in the 220-kV plant is illustrated in Fig. A. The stationary contacts are of the double-brush type, whilst the movable ones are expansion blocks. In closing, the current-carrying rod is first rotated; at the end of the rotation the central column dislodges a toothed rod which rotates a toothed wheel; by means of a screw, this wheel presses the expansion block against the elastic brushes of the stationary contacts, without exerting bending stresses on the insulators of the side columns. In opening the switch, the operations take place in the reverse order.

As Mr. Harle rightly observes, the use of bushings of the condenser type for "metering" purposes would give incorrect results. In Italy also these methods have so far been used solely for reading voltages. As regards lightning arrestors, I confirm that in the latest very high-voltage plants they have generally been eliminated.

THE DIELECTRIC PROPERTIES OF VARNISHED CLOTH AT LOW VOLTAGE-GRADIENTS.[*]

By L. HARTSHORN, D.Sc.

[From the National Physical Laboratory.]

[REPORT (REF. L/T44) OF THE BRITISH ELECTRICAL AND ALLIED INDUSTRIES RESEARCH ASSOCIATION.]

(*Paper received 4th September, 1931.*)

PREFACE.

A knowledge of the nature of the insulating properties of insulating materials is obviously of the first importance to electrical engineers. Hitherto that knowledge has been highly empirical.

In a previous report (Ref. L/T14)[†] it was shown that there was reason to expect certain simple relations between absorption phenomena and dielectric loss phenomena, between observations made on direct current and alternating current, and that the properties concerned were few in number and might be separately evaluated.

The Association set out to apply these ideas to commercial insulating materials. The present report shows that they are applicable and it applies them within a wide range of voltage stress to certain materials in general use.

The question then arises: Are the results obtained applicable to working stresses? For it is found that if the materials tested are stressed beyond certain limits, changes (probably destructive) take place and departures occur. These changes are still under investigation, but it is important to note that they lie in a region of stress above that normally reached in practice. It is well known (see, for example, report Ref. L/T26[‡]) that in practice stresses are limited by considerations of thermal balance more often than by the ultimate strength of the material stressed.

We have here, then, already a fundamental analysis of properties that applies to working conditions.

The results reported represent several years' work, the investigators having to develop their own technique and overcome numerous experimental difficulties.

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  Conclusions.
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SUMMARY.

Measurements of the dielectric properties of typical samples of varnished cloth have been made with the object of studying the laws governing the dissipation of power in the material when it is subjected to an alternating voltage.

All the measurements were made under carefully controlled conditions. The samples were conditioned and tested in an enclosure, which was approximately airtight, and the temperature and humidity were regulated as required. An arrangement of mercury electrodes was

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[*] The Papers Committee invite written communications, for consideration with a view to publication, on papers published in the *Journal* without being read at a meeting. Communications (except those from abroad) should reach the Secretary of the Institution not later than one month after publication of the paper to which they relate.

[†] *Journal I.E.E.*, 1926, vol. 64, p. 1152.

[‡] *World Power*, 1928, vol. 10, p. 622.

generally used, but a number of control experiments made with graphite electrodes showed that the properties observed were those of the material itself, and were not peculiar to any one type of electrode.

The most important measurements made were those of permittivity and power factor (from which the power loss was calculated), but measurements were also made, in certain cases, of the absorption and leakage currents produced by a constant applied voltage, with the object of correlating the results of alternating- and direct-current measurements.

The permittivity and power factor were found to be independent of the voltage for all voltage gradients less than a certain critical value, and the present investigation was confined to this range of voltage gradients, which includes the values commonly employed in practice.

The methods of measurement include the Schering bridge, a resistance bridge found to be more convenient in cases where the power factor was very large (values greater than 90 per cent were found), and an electrometer method for the d.c. experiments. The corrections and precautions necessary for high accuracy were studied in detail.

The variations of the dielectric properties with atmospheric humidity, temperature and frequency of the applied voltage, have been investigated, and curves representing the more important results are given. Within the frequency range 50 to 4 000 cycles, the majority of the results obey the equations first given by Hopkinson and afterwards by Schweidler, and it is shown that the properties of such samples can be represented by four fundamental constants, the values of which are tabulated. These constants will represent d.c. as well as a.c. observations, but only when the time of electrification is short, i.e. of the same order as the periodic time of the alternating current.

The general conclusion reached is that the current responsible for the power loss in varnished cloth is carried by ions or dipoles, the motion of which is opposed by a frictional force depending on the viscosity of the material or some similar property; that the displacement of such ions or dipoles conforms to Hopkinson's superposition principle, and that there is no dielectric hysteresis analogous to magnetic hysteresis. No existing theory gives a completely satisfactory explanation of the equations representing the observations, but the statistical explanation of K. W. Wagner, when applied to several possible theories, will account for them to some extent.

I. Introduction.

This investigation was started some years ago with the object of obtaining some insight into the processes involved in the dissipation of power in dielectrics under the action of alternating voltage. Varnished cloth was selected as being typical of a fairly large class of dielectrics in general use, and it was hoped that the data acquired during the course of the investigation would therefore also be of immediate practical value. The information already in existence was very meagre, and full of inconsistencies, probably due to the fact that the experimental conditions were not sufficiently well defined. In the following experiments, particular attention was paid to this point.

II. The Apparatus for Conditioning and Testing the Samples.

The Test Enclosure.

It is known that most insulating materials are, to some extent, hygroscopic, and that when a dried material is allowed to come into contact with ordinary air, the change in the moisture content of the material is often extremely rapid at first. In devising apparatus for the general testing of dielectrics, it was therefore considered essential to provide means for making tests in an air-tight enclosure. Such an arrangement was constructed (Fig. 1). It consists of a box 12 in. × 12 in. × 16 in., made from copper sheet, and fitted with a dew-point hygrometer H, thermometer T, and small motor-driven fan F for stirring the air. In order to make the enclosure as nearly air-tight as possible, the hygrometer and thermometer were fitted into tightly fitting rubber bungs, and the spindle of the fan was provided with a long bearing, which was kept well lubricated. The front of the enclosure was of plate glass and hinged to form a door. The fitting of this door was made air-tight by placing in a channel round the front edge of the box a gasket consisting of a rubber tube, which was inflated after closing the plate-glass door.

The enclosure could be heated by resistance mats supported in clips on the outside of the walls. The lagging was formed of shallow boxes made from uralite sheet and filled up with magnesia. These were bolted to the sides of the box. Holes were made through the lagging where it was necessary to allow the fitting of the thermometer, fan, electrodes, etc. The temperature was accurately controlled by means of a regulator R, which was filled with transformer oil. This was found to be very convenient for obtaining constant temperatures up to 100° C. The temperature control was carried out by means of additional resistance mats mounted inside the enclosure at the back, as the time-lag associated with the action of the outside mats made it impossible to avoid cyclic temperature fluctuations when they were used for this purpose.

The humidity of the air in the enclosure was controlled by means of dishes of various absorbing reagents placed in the enclosure in such a position that the fan blew the air over them. Caustic potash and calcium chloride were occasionally used, but sulphuric acid of various strengths was found to be most convenient for producing any desired humidity. Tables* are available giving the humidity corresponding to acids of various strengths, but the actual humidity was always measured by means of the dew-point hygrometer. In certain experiments, after using calcium chloride as the drying agent, the insulating washers of the electrodes were found to have become contaminated with particles of calcium chloride, presumably deposited on them by the action of the fan. The leakage due to this contamination was found to vary considerably with the applied voltage and introduced errors which were at first very difficult to explain. The use of this material is therefore not recommended.

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* H. L. Curtis: *Bulletin of the Bureau of Standards*, 1915, vol. 11, p. 367.

The Electrodes.

In a previous investigation* a study of the degree of contact obtained by the use of various arrangements of electrode was made, and it was decided that the most satisfactory electrode for an investigation of this kind was the mercury electrode. In the previous experiments the sample was clamped between two ebonite plates, in which were cut recesses, which could be filled with mercury. It was found to be essential to mount the sample in a vertical position and to run in the mercury from below, slowly, the displaced air being allowed to escape through holes at the top.

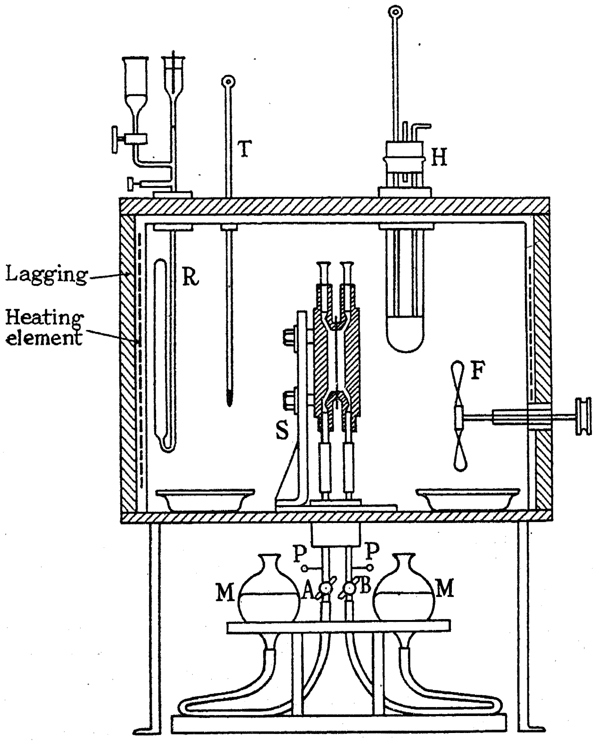

FIG. 1.—Test enclosure, showing electrode assembly in position.

An improved form of electrode-clamp, embodying these features, was designed for the present investigation. In order to avoid errors due to the losses in the ebonite, the clamps were made of cast iron. This was chosen since it is not attacked by mercury. Copper or brass are inadmissible since they dissolve in the mercury and the resulting amalgam tends to oxidize and thus to develop a high surface resistance, which may cause an apparent increase in the power factor of the sample. The actual arrangement is shown in Fig. 2. The clamps consist of two cast-iron blocks in which are cut shallow recesses to hold the mercury. The rims of these recesses were only 1 mm wide, and were made accurately flat so that when the arrangement was tightened up they formed a good fit. The sample was clamped between the two cheeks by means of four bolts and nuts, one of which is shown in the diagram. These were attached to lugs, uniformly spaced round the clamps. The bolts were rigidly attached to one cheek and passed through insulating washers in the other. The mercury could be passed in from below through the glass tubes T_1, which were cemented into sockets in the castings. Shellac, applied as varnish, was found to be the most satisfactory cement for this purpose. After baking, it was very strong and quite satisfactory at temperatures up to 100° C. The air displaced by the mercury escaped through the glass tubes T_2 at the top. The mercury was just visible in these tubes when the clamps were completely full.

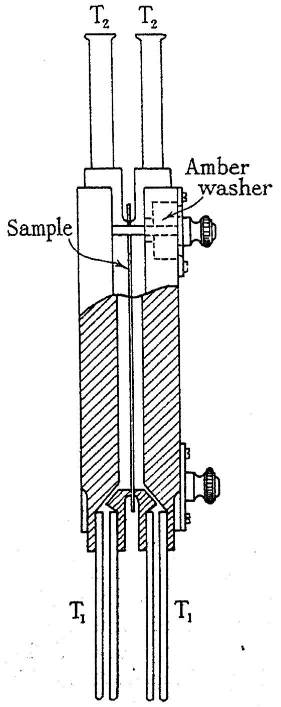

FIG. 2.—Mercury clamps forming the electrode assembly shown in Fig. 1.

Two such sets of electrodes were used. The first, shown in Fig. 2, provided circular electrodes of diameter 7·2 cm (including the narrow cast-iron rim). The insulation of these clamps consisted of four amber washers. The second set of electrodes was used for larger and thicker samples. Their diameter was 15 cm. They were very similar to the smaller clamps, but were provided with six bolts and nuts for clamping up, instead of four. The insulating washers in the larger clamps were of fused quartz. They were made by cutting off short lengths from a piece of quartz tubing and were cemented in position with shellac.

The manner in which the clamps were fitted into the enclosure is shown in Fig. 1. Two glass tubes, A, B, were fitted into a bung in the bottom of the enclosure. These tubes were provided with stopcocks and were connected by means of rubber tubing to the mercury reservoirs M. The tubes, A, B, projected inside the enclosure and were there connected to the glass tubes fitted into the bottoms of the clamps by means of short lengths of rubber tubing. The weight of the clamps was taken by a stand S. The electrodes were insulated from the stand by means of washers of ebonite or keramot. Thus the walls of the enclosure could be connected to earth so as to form a screen, without necessarily at the same time connecting either electrode to earth. The electrical connections to the sample were made by means of short lengths of platinum wire P (Fig. 1) sealed into the glass tubes A and B above the stopcocks.

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* D. W. DYE and L. HARTSHORN: *Proceedings of the Physical Society*, 1924, vol. 37, p. 42.

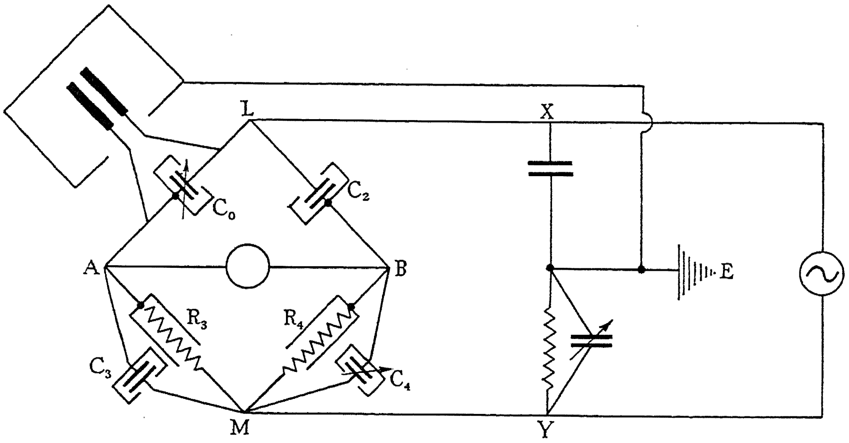

FIG. 3.—Wagner earth-connection XYE and Schering bridge network.

Procedure in Conditioning Samples.

The air in the enclosure was readily brought into any desired condition of temperature and humidity by setting the temperature regulator to the required point, putting into the enclosure a dish of sulphuric acid of the appropriate strength and starting the fan. It was found that the relative humidity of the air reached its final constant value in about an hour.

When, however, a sample of varnished cloth was placed in the enclosure and tested at intervals, its properties were found to vary very slowly, but the change continued for many hours. Three or four days were usually taken by a sample to reach an equilibrium condition, and therefore all samples were hung in the enclosure for at least three days before beginning any series of tests. When the sample was inserted in the clamps, its access to the air was, of course, somewhat restricted, but the air actually in contact with the sample, i.e. inside the clamps, could readily be changed by raising and lowering the mercury reservoirs, and thus alternately filling the clamps with mercury and emptying them.

III. THE MEASUREMENT OF PERMITTIVITY AND POWER FACTOR UNDER VARIOUS ATMOSPHERIC CONDITIONS.

The Schering Bridge.

The measurements of the capacity and power factor of the samples were in most cases made by means of the Schering bridge, Fig. 3. This is now so well known that a detailed description is unnecessary, but in order to obtain the highest possible accuracy, especially at the higher frequencies employed (8 000 cycles), a Wagner earth-connection XYE (Fig. 3) was used for many of the experiments, and the measurements were, whenever possible, made by a substitution method in terms of a standard variable air condenser, C_0. It is to be noted that all the bridge components were shielded, the shields being all connected either directly to earth or to a point on the network at earth potential (A or B, Fig. 3). For most of the measurements C_0 was a standard variable air condenser of maximum value 2 000 $\mu\mu$F, C_2 was a fixed condenser of 2 000 $\mu\mu$F, R_3 and R_4 were each 1 000 ohms, C_4 consisted of a three-dial mica condenser of maximum value 1 μF, variable in steps of 0·001 μF, supplemented by a variable air condenser of maximum value 0·001 μF, for fine adjustments. For measurements at the higher frequencies, the mica condenser could be dispensed with. C_3 was a very small fixed condenser, just sufficiently large in capacity to balance the minimum reading of C_4, when the sample was disconnected from the bridge.

The equations of balance of the bridge may be written

$$C_1[1 + R_4C_4\omega \tan\delta_1] = \frac{R_4}{R_3}C_2 + R_4R_3C_2\tan\delta_2 \quad (1$$

$$\tan\delta_1 = \frac{R_4}{R_3}\frac{C_2}{C_1}\tan\delta_2 + \frac{\omega R_4}{C_1}(C_1C_4 - C_2C_3) \quad . \quad (2)$$

where C_1, C_2, C_3, C_4, represent the total capacities in the arms of the bridge AL, LB, AM, and MB respectively, and δ_1, δ_2, are the loss angles associated with C_1 and C_2 respectively. The capacity C_3 should be made as small as possible (zero, if possible). If this is done, and the values of tan δ_2 and tan δ_1 are not large, equation (1) may be written, approximately

$$C_1 \doteqdot \frac{R_4}{R_3}C_2 \quad . \quad . \quad . \quad . \quad . \quad (3)$$

and substituting this approximation in the small terms in (2) we obtain the more convenient equation

$$\tan\delta_1 = \tan\delta_2 + \omega R_4C_4 - \omega R_3C_3 \quad . \quad . \quad (4)$$

The resistance ratio-arms R_3 and R_4 will not in general be perfectly non-reactive. Their phase angles will affect the values of C_3 and C_4. If therefore we wish C_3 and C_4 to represent only capacities added to the arms R_3 and R_4, we must include in (4) a term θ_{34}, representing the phase angle of the resistance ratio-arms. The complete working equation thus becomes

$$\tan\delta_1 = \tan\delta_2 + \omega R_4 C_4 - \omega R_3 C_3 + \theta_{34} \quad . \quad (5)$$

The substitution method of working has the advantage of eliminating the unknown terms $\tan\delta_2$ and θ_{34}.

Procedure—The Substitution Method.

The platinum wires P (Fig. 1) were permanently connected to the arm AL of the bridge (Fig. 3). The samples being in position, the reservoirs M were raised so as to cause mercury to flow slowly into the clamps. When the arrangement was full, the stopcocks in A and B were closed, thereby insulating the mercury in the clamps from that left in the reservoirs. The bridge was then balanced and the readings of the condensers C_0 and C_4 noted. The stopcocks were then opened and the mercury allowed to run out until it stood just above the level of the platinum wires P, but below the clamps. The stopcocks were then again closed. In this way the sample was disconnected from the bridge, but the connecting leads and mercury tubes were left connected as before. The bridge was again balanced by adjusting C_0 and C_4. Let the first readings of C_0 and C_4 be C_0' and C_4', and the final readings be C_0'' and C_4''. Let G_x represent the conductance of the sample in the clamps, and C_x its capacity at the frequency $\omega/(2\pi)$. Let C_l represent the capacity of the leads to the clamps, and G_0 represent the conductance of the insulating supports on the condenser C_0 and the leads to the clamps. This will be very small compared with G_x. The equations for the two measurements may now be written down by substituting these values in (1) and (5). Subtracting the two equations obtained from (1), and also those from (5), we find that the constant terms involving C_2, $\tan\delta_2$, and θ_{34}, disappear and we are left with

$$\begin{aligned}(C_x + C_l + C_0')(1 + R_4 C_4'\omega\tan\delta_1)\\ - (C_l + C_0'')(1 + R_4 C_4''\omega\tan\delta_0) = 0 \quad (6)\end{aligned}$$

$$\begin{aligned}&\tan\delta_1 - \tan\delta_0\\ &= \frac{G_x + G_0}{(C_x + C_l + C_0)\omega} - \frac{G_0}{(C_l + C_0'')\omega} = \omega R_4(C_4' - C_4'') \quad (7)\end{aligned}$$

In these equations, $\tan\delta_0$ represents the very small power factor due to G_0 in the arm AL when the sample is disconnected. It is to be remembered that $\tan\delta_1$ is usually small and that $\tan\delta_0$ is much smaller. C_l is also very small. In many cases we may neglect the small correcting terms in these expressions and write

$$C_x = C_0'' - C_0' \quad . \quad . \quad . \quad . \quad (8)$$

$$\tan\delta_1 = \omega R_4(C_4' - C_4'') \quad . \quad . \quad . \quad (9)$$

and

$$\tan\delta_x = \frac{G_x}{C_x\omega} = \omega R_4(C_4' - C_4'')\frac{C_0''}{C_x} \quad . \quad . \quad (10)$$

If a closer approximation is desired, we may, instead of neglecting the small terms involving $\tan\delta_1$ in (6) and G_0 in (7), substitute the approximate expression (8) and (9) in them. We then obtain the more accurate equations

$$\begin{aligned}C_x &= C_0'' - C_0' - C_0'' R_4 C_4'\omega\tan\delta_1\\ &= C_0'' - C_0' - C_0'' R_4^2 C_4'(C_4' - C_4'')\omega^2 \quad . \quad (11)\end{aligned}$$

$$\tan\delta_x = \omega R_4(C_4' - C_4'')(C_x + C_l + C_0')/C_x \quad . \quad (12)$$

The values of the capacity and power factor of the sample under investigation were usually calculated by means of equations (8) and (10), but equations (11) and (12) were used for samples of high power factor, for which the correcting terms were appreciable. The capacity of the leads C_l was measured by a similar substitution measurement on the same bridge, but it was usually negligibly small.

The "Edge-Capacity" Correction.

A sheet of insulating material mounted in a pair of the clamps filled with mercury, forms a condenser which may, as a first approximation, be regarded as a simple flat-plate condenser, and the permittivity (κ) of the material may be calculated from the formula—

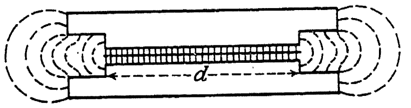

FIG. 4.—Flux leakage through air at edge of clamps.

$$C_x = A\kappa/(3\cdot 6\pi t) \quad . \quad . \quad . \quad . \quad (13)$$

where

C_x is the capacity in micro-microfarads;
A is the area of the sample in contact with each metal electrode in cm^2;
t is the thickness of the sample in cm.

This calculation assumes that the whole of the lines of force between the electrodes cross the sample at right angles to its surface, and are uniformly distributed across it, which will be very nearly true for the area A of the sample, but it is obvious that there will also be lines of force, mainly in air, bridging the clamps at their edges, as shown in Fig. 4. Thus the total capacity of the clamps C may be regarded as consisting of two parts, the capacity of the sample C_x and the "edge capacity" C_e. We then have

$$C = C_x + C_e = A\kappa/(3\cdot 6\pi t) + C_e \quad . \quad . \quad (14)$$

It is evident that in order to calculate the permittivity of any sample from the bridge readings, the edge capacity must be known. It will obviously depend only slightly on the nature of the sample in the clamps, but it will depend on its thickness. The values of edge capacity corresponding to a few representative thicknesses were measured by the method described below, and the values obtained were used for the calculations of permittivity. The capacity of the connecting leads was for convenience included with the edge capacity, and the combination was treated as C_l in equations (6) to (12).

The method of measuring the edge capacity may be understood by reference to Figs. 4 and 5. In Fig. 4 the capacity of the sample C_x is represented by the lines of force lying within the circular area (A) of diameter d. The edge capacity C_e is represented by all the lines of force (shown dotted in Fig. 4) lying outside this area. If now a circular piece of thin metal foil, of diameter d, is placed between the clamps, but insulated from them, as in Fig. 4, all the lines of force of the capacity C_x will impinge on it, and all those of C_e will not touch it. If the foil is midway between the clamps and of negligible thickness, the result is a capacity $2C_x$ between each clamp and the circular piece of foil, and a capacity C_e between the clamps. If now the clamps are connected to the bridge as in Fig. 5, the piece of foil being connected to the earthed point E by means of a fine wire, the two capacities $2C_x$ between the clamps and the piece of foil are eliminated from the capacity measurements by means of the Wagner earth connection. Thus if two balance points of the bridge are obtained, (1) with the connections described, and (2) with the clamps disconnected from the bridge, the difference between the two readings of C_1 gives the edge capacity C_e directly. If the disconnection is made at the points A and C, the capacity of the leads will be included in the measurement. The disc of thin foil was placed between two sheets of mica, and the whole placed in the clamps as usual. By using various thicknesses of mica, the variation of edge capacity with thickness was investigated. The results are shown in Table 1.

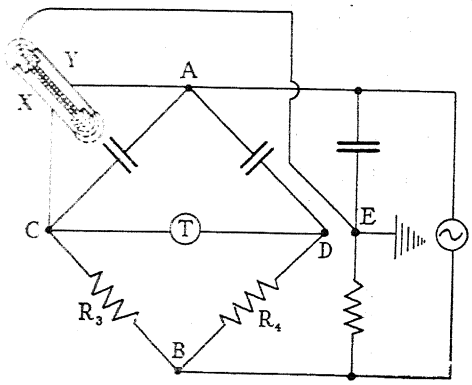

FIG. 5.—Bridge for the direct measurement of edge capacities.

When these edge-capacity corrections were applied, measurements of permittivity made by means of the two sets of electrodes on samples cut from the same sheet of material gave concordant results, e.g. for a certain sheet of material a value of 7·18 was obtained with the large clamps and values of 7·16 and 7·13 for two samples in the small clamps. The differences may be accounted for by uncertainties in the determination of the mean thickness.

TABLE 1.

Edge Capacities of the Electrodes.

Clamps	Thickness of sample, mm	Edge capacity	
		Including mercury tubes, μμF	Clamps only, μμF
Small ..	0·23	19·9	18·0
	0·48	19·6	17·8
	1·5	—	(17)
Large ..	0·31	42·9	41·8
	3·0	—	(37)

The Power Loss in the Clamps Themselves.

A determination of the small amount of power loss occurring in the insulating washers of the clamps themselves was made as follows: The clamps were separated so that their rims were a definite distance apart, say 1 mm. No sample was inserted, so that they formed a small air condenser. The capacity and power factor of the condenser was measured by the method already described, the only modification being that connection and disconnection to the bridge were in this case made by means of terminals instead of the mercury arrangement. The small clamps were found to possess a conductance of 170 × 10^{-12} mho at 1 000 cycles. This represents the power loss in the amber washers. For a measurement on a sample of capacity 1 000 μμF, it would introduce an error in power factor of 3 × 10^{-5}. This is, of course, in general, negligible, but the correction can easily be applied when necessary. The losses in the quartz pillars of the large clamps were found to be even less than this amount.

This measurement also provided a check on the edge-capacity determination. The capacity between the effective area A of the clamps was calculated approximately from the formula

$$C = A/(3\cdot 6\pi t)\ \mu\mu\mathrm{F}$$

t being the distance between their plane faces. The difference between this value and the measured value of the capacity gives the edge capacity of the clamps for the spacing used. The values so obtained are shown in brackets in Table 1. The agreement between the two methods is quite satisfactory.

The Applied Voltage.

The impedances of the resistance arms of the bridge were always comparatively small, so that the voltage across the sample was practically equal to the voltage applied to the bridge, which was usually of the order of 100 to 200 volts. Several series of tests were made in order to find out the effect of a varying voltage on the bridge readings. The results showed that when testing a single sheet of varnished cloth, the voltage can be varied from about 20 volts to 300 volts without affecting the readings by more than 1 part in 1 000. The changes occurring at higher voltages will be dealt with later, but it may be taken that as long as the applied voltage does not exceed 40 volts per mil the permittivity and power factor are independent of the voltage. Thus in carrying out a series of tests under varying conditions, it was not necessary to control and measure the voltage. It was sufficient to know that it was of the order of 100.

Reproducibility of Results.

It is obviously of great importance to know to what extent the results obtained for any one material are reproducible, as slight changes in temperature, humidity, and the degree of contact of the electrodes may all affect the results. Information on this point was obtained by two series of observations. For the first, measurements were made daily for about a week on a sample of varnished cloth L101, in a dry atmosphere at 20° C. The mean values of permittivity and power factor were 4·48 and 0·0380 respectively. The maximum deviation of any single result from the mean was 1 per cent, for both permittivity and power factor. On any one day the values could be repeated with a discrepancy of no more than 0·0001 in power factor and 0·2 per cent in permittivity. The second set of observations was made on the same material in an atmosphere of relative humidity 75 per cent at 20° C. The mean values of permittivity and power factor were 6·58 and 0·162 respectively, and the maximum deviation of any single result from the mean was 0·5 per cent for both permittivity and power factor, the observations lasting over two days in this case.

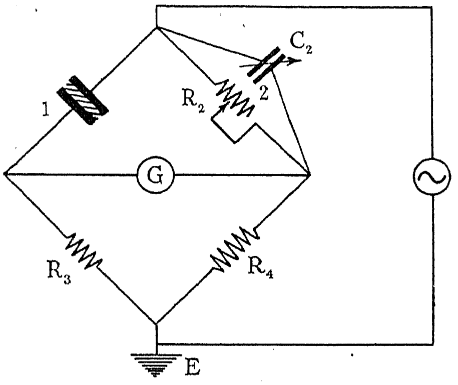

FIG. 6.—Bridge for measurements on materials of very high power factor.

Comparative measurements were also made on several samples cut from the same sheet of cloth. The maximum deviation of any result from the mean was 1 per cent for permittivity (mean value 6·60) and 0·3 per cent for power factor (mean value 0·161).

The Measurement of Very Large Power Factors.

When measurements were made on samples of high moisture content at high temperatures, values of power factor of 90 per cent and over were obtained. The Schering bridge was found to be not very convenient for the measurement of capacity and power factor under these conditions; the two bridge adjustments were no longer even approximately independent of one another, and the process of balancing the bridge by successive approximate adjustments became very tedious. The sample behaves more like a resistance than a capacity, and the simple resistance-capacity bridge shown in Fig. 6 was found to be much more suitable for measurements on such materials.

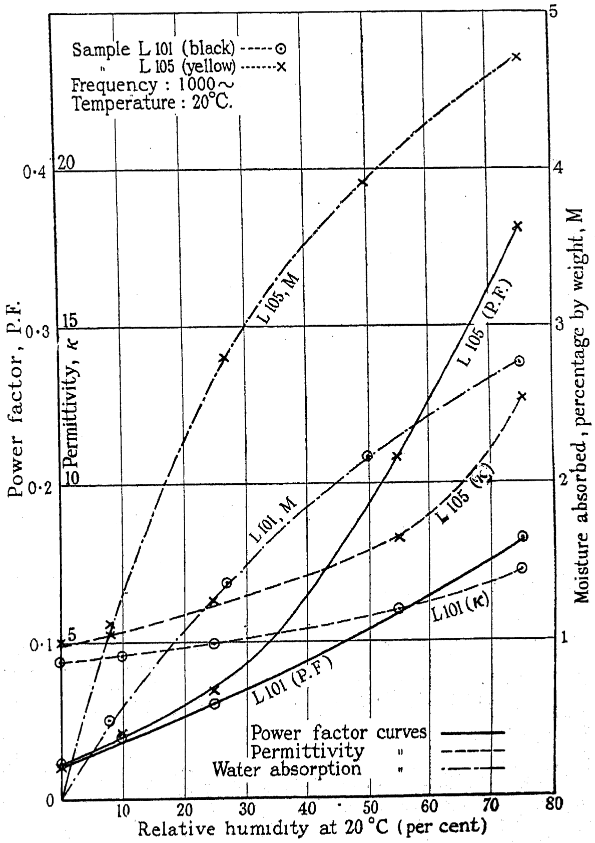

FIG. 7.—Permittivity, power factor, and moisture absorption as a function of atmospheric humidity.

The sample was connected to arm 1 of the bridge. Arm 2 consists of a standard variable air condenser C_2 and a variable non-reactive resistance of high value R_2 in parallel. The other two arms consist of a pair of non-reactive resistance ratio coils R_3 and R_4. It is obvious that if we neglect small corrections, the capacity of the sample is given by R_4C_2/R_3 and its conductance by $R_4/(R_3R_2)$. For R_2 a resistance box having a maximum value of 100 000 ohms was used. The resistance ratio R_4/R_3 was chosen so that the particular sample under test gave a convenient reading of R_2. In general the values of both R_3 and R_4 were between 500 and 5 000 ohms.

When the highest possible precision is required, a Wagner earth connection should be applied to this bridge and corrections must be made for the residual inductances of all the resistance coils. This was, however, found to be quite unnecessary for the experiments on insulating materials of very high power factor; the properties of the material change so rapidly with changing conditions that very high accuracy is of no importance. The simple earth connection shown in Fig. 6 was therefore used, and the small corrections were neglected.

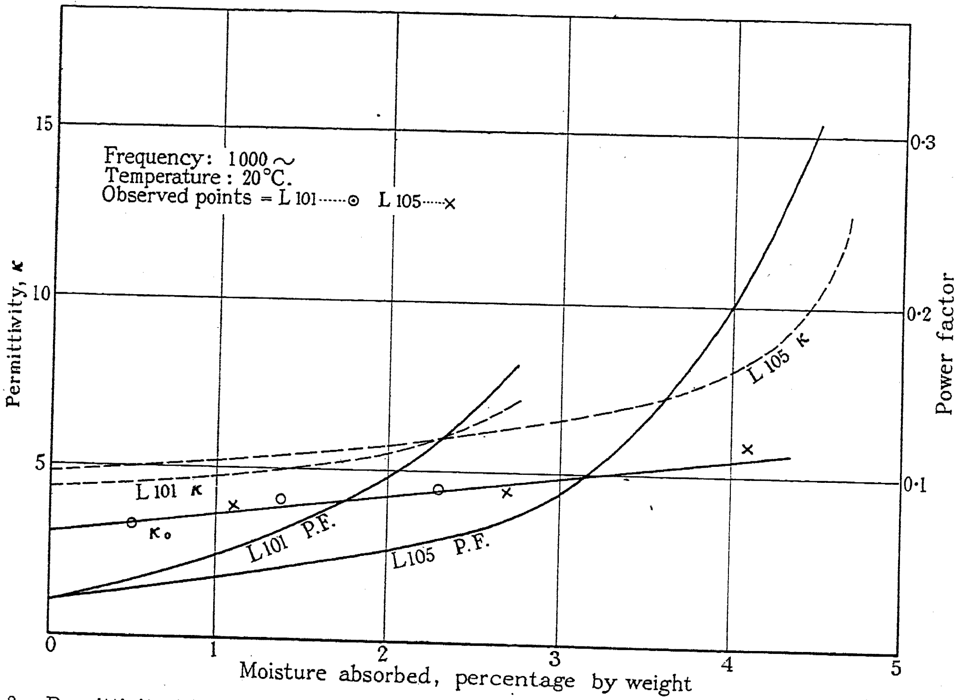

FIG. 8.—Permittivity (κ) power factor (P.F.) and dielectric constant (κ_0) as functions of moisture absorbed.

IV. PERMITTIVITY, POWER FACTOR AND MOISTURE CONTENT, AS A FUNCTION OF ATMOSPHERIC HUMIDITY —RESULTS.

The Effect of Varying Relative Humidity.

Samples of eight kinds of varnished cloth were maintained at a constant temperature in an atmosphere the relative humidity of which was varied in stages from the driest obtainable in the enclosure by the use of concentrated sulphuric acid (about 8 per cent), up to 75 per cent. At each stage sufficient time was allowed for the materials to reach an equilibrium condition. The permittivity and power factor of each sample were then measured at a frequency of 1 000 cycles. The results for two of the samples are shown in Fig. 7. These two materials gave the highest and lowest values respectively of permittivity and power factor; the curves for the other materials were between these two and are therefore omitted for the sake of clearness. It will be observed that both permittivity and power factor are very greatly affected by the humidity, especially in the region of the ordinary room condition (50–75 per cent). Generally speaking, the yellow materials possessed a higher permittivity and power factor than the black ones in the same atmosphere, but this was not true in every case.

The Moisture Content of the Material.

The weight of each sample was measured in each of the equilibrium conditions, and from the results the changes in moisture content were determined. By plotting these changes against relative humidity and extrapolating the curves so obtained to the axis of zero relative humidity, the curves (M) of Fig. 7 were obtained. These are considered to represent the total free-moisture content of the samples. The extrapolation is admittedly somewhat uncertain, but it provides a convenient means of obtaining an approximation to the true curve. The curves of Fig. 8 show the relation between the permittivity and power factor of the sample and the weight of water absorbed by it.

It is to be noted that the comparatively high permittivity and power factor of the yellow sample L105 under ordinary room conditions are due to the fact that it absorbs much more water than the black sample. In the perfectly dry condition the two materials have practically the same values of permittivity and power factor, and if they are made to absorb the same percentage by weight of water, the black material actually becomes the poorer. Another striking fact is that the addition of only 1 per cent by weight of water causes but a slight change in electrical properties, but the addition of 3 or 4 per cent causes a relatively enormous change. This strongly suggests that the added water takes up a different form or distribution as the amount is increased. For example, the first traces of water may be adsorbed by the surfaces of the fibres, and thus form a network of surface films, the properties of which may be very different from those of water in bulk. As the amount of water is increased, thicker films with properties approximating more and more nearly to those of ordinary water may be expected to form, or there may be a tendency to form more or less separate droplets. Whatever the process may be, it is fairly certain that important changes occur when the weight of water absorbed is of the order of 2 to 4 per cent.

The Effect of Prolonged Heating.

A second set of samples was maintained at a temperature of about 117° C. for 48 hours with the object of driving off all moisture, and then inserted in the clamps and tested as quickly as possible. The results obtained were found to agree with the points on the curves of Figs. 7 and 8, corresponding to zero relative humidity and zero moisture content. Generally speaking, the observed values were slightly greater than those obtained by extrapolating the curves to the axis of zero relative humidity. The observed values are plotted on this axis in Fig. 7. After the heating the yellow cloths were found to be darker in colour, and all the samples were less limp than before. A permanent change in the varnish had therefore probably occurred and on this account these samples were not again used. It is, however, evident that heating produces a higher degree of dryness than can be obtained by drying agents at low temperatures.

The Effect of Several Layers.

All the values of permittivity and power factor mentioned above were obtained from measurements on a single sheet of material. In practice several layers are used, and in order to find out how the properties of the material are modified under these conditions, an additional series of measurements was made on material L101 in equilibrium with an atmosphere of relative humidity 75 per cent at 20° C., and in thicknesses of one to five layers. The large mercury clamps were used for these experiments in order to obtain a sufficiently large capacity with the larger thicknesses.

When the mercury was first run into the clamps, two or more sheets being in position, the mercury level was observed to fall slowly. This went on for half-an-hour or more. The explanation is that the pressure of the mercury gradually brings the sheets into intimate contact, the entrapped air being slowly forced out by way of the edges of the samples. While this process was occurring, the capacity of the arrangement continued to increase, but eventually a constant value was reached, indicating that the sheets had reached their final contact condition. If after this the mercury was withdrawn from the clamps and then replaced, no further changes of level or capacity were found to occur. When the sample was removed from the clamps the various layers were firmly stuck together, and there appeared to be no air bubbles between them. When the sheets were pulled apart a slight tearing sound was noticed, indicating that the contact between them must have been intimate.

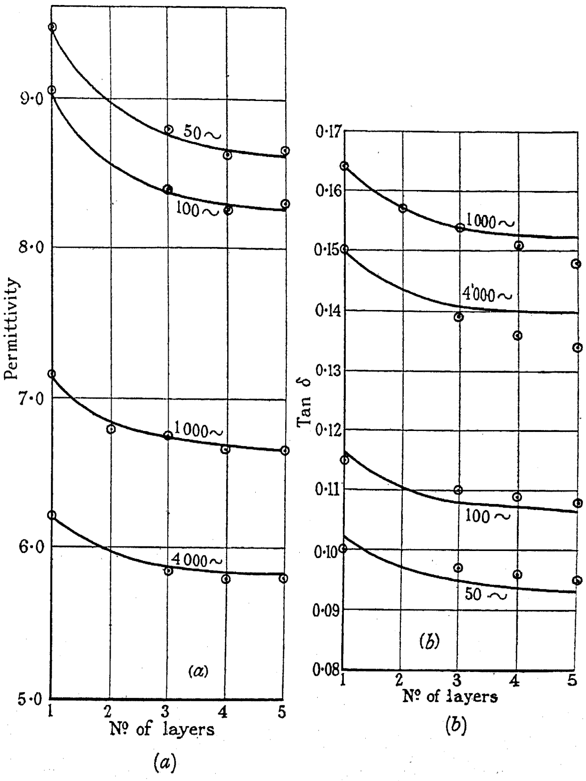

FIG. 9.—Permittivity and power factor as a function of number of layers.

The results are shown in Fig. 9. Both the permittivity and tan δ decrease as the number of layers is increased. The explanation of this variation is to be found in the existence of a very thin air film between adjacent layers. Assume for the moment that the layers of varnished cloth are each of thickness t_1, and that they are separated by air films of mean thickness t_0. The actual thickness measurements were made by means of an ordinary micrometer, and to an accuracy of 0·01 mm the thickness of a number of layers was found to be equal to the sum of the thicknesses of the individual layers, and this was assumed to be the case in calculating the permittivity results. On these assumptions it is easy to show that at any frequency the permittivity κ, of n layers, each of thickness t_1, separated by $n - 1$ air films each of thickness t_0, is given by

$$\frac{1}{\kappa} = \frac{1}{\kappa_1} + \frac{n-1}{n} \frac{t_0}{t_1} \quad . \quad . \quad . \quad . \quad (15)$$

where κ_1 is the permittivity of a single layer at the same frequency. By plotting the observed values of $1/\kappa$ against $(n - 1)/n$, a series of straight lines of approximately constant slope was obtained. This constant slope gives the value of

$$t_0/t_1$$

and it was found that

$$t_0/t_1 = 0{\cdot}013$$

Thus the thickness of the air films is 1·3 per cent of that of the cloth, i.e. 0·0026 mm or 0·1 mil. The curves drawn in Fig. 9(*a*) are calculated from equation (15) on the assumption that t_0 has this value. The differences between the observed and calculated results are within the experimental error. It is to be noticed that the calculation assumes that there is no air film between the electrode and the material. The results show that the thickness of the air film between adjacent layers must exceed twice that between the electrode and the material by 0·0026 mm.

If we assume that the air film between layers is of zero power factor, we find that the power factor tan δ of *n* layers is given by

$$\tan\delta = \tan\delta_1\bigg/\left(1 + \frac{n-1}{n}\kappa_1\frac{t_0}{t_1}\right) \quad . \quad . \quad (16)$$

where tan δ_1 is the power factor of a single layer. When the value of

$$t_0/t_1$$

previously found was inserted in this equation, it was found to give the curves shown in Fig. 9(*b*). The discrepancies between observed and calculated results appear to be rather larger than the experimental errors, but it is evident that the greater part of the variations observed are explained by the existence of an air film of very low power factor. The discrepancies are probably to be accounted for by the conductance of this film, which will affect the power factor by unequal amounts at the different frequencies.

The Effect of Using Graphite Electrodes.

It is known that permittivity and power-factor measurements are affected by the degree of intimacy of contact of the electrodes used, and that in this respect rigid metal plates and sheets of tinfoil are unsatisfactory as electrodes. It has been shown above that the contact obtained by mercury is reproducible to a high degree of accuracy, and it is believed that in experiments such as those described here, it may be regarded as giving a practically perfect contact. Dr. Daynes,* of the Rubber Research Association, has developed a technique for the use of electrodes of graphite. The insulating material is painted with "Aquadag," a suspension of colloidal graphite in water; the water is allowed to evaporate, and the film of graphite which is left is used as the electrode. It has been shown that graphite in this form, and also in the form of a dry powder, "Leiterit," which is merely rubbed on the sample, will make a very good electrical contact with many materials, and it was therefore of great interest to see whether the results obtained with this type of electrode-contact were the same as those obtained with mercury.

Several samples of varnished cloth were conditioned and tested by the usual method. Some of them were then coated with Aquadag, others with Leiterit and others left unaltered. The samples coated with Aquadag absorbed water and they only reached their original equilibrium condition again after being left for several days in the constant temperature enclosure. When this had been done, the samples were again placed in the clamps, which were filled with mercury, and measurements of permittivity and power factor were made as before. The differences between the results for the same sample with and without graphite were no greater than the differences between the results for the samples which had been left untouched, but which had been left in the enclosure with the graphite-coated samples to provide a control test. It is concluded that the intimacy of contact obtained with clean mercury and graphite is sensibly the same, and that the results now given may be regarded as representative of the insulating material itself, apart from any question of electrodes.

V. THE VARIATION OF PERMITTIVITY AND POWER LOSS WITH FREQUENCY—HOPKINSON'S EQUATIONS.

Observations at Various Frequencies.

The variation of dielectric properties with frequency may be expected to yield important information as to the nature of the processes involved. A study was therefore made of the variation with frequency of the permittivity and tan δ of varnished cloth at various temperatures, and with various amounts of absorbed water. The frequencies used varied from 50 cycles to 8 000 cycles, and the material was tested at temperatures ranging from 20° C. to 90° C., and with free-moisture contents of about 0·5 to 4 per cent by weight, corresponding to equilibrium with atmospheres of relative humidity 8 per cent to 75 per cent at 20° C.

The procedure was as follows. The samples were first brought into equilibrium with an atmosphere of definite humidity at 20° C. Measurements of permittivity and tan δ were then made at each of the frequencies required. The temperature of the enclosure was then raised to 30° C., and another set of measurements of permittivity and tan δ at the various frequencies was made. Similar observations were then made at temperatures of 40°, 60°, and 90° C. The temperature was maintained at a constant value for several hours before beginning any one set of observations. The mercury was maintained in contact with the sample for the whole of the time during which the observations at the different temperatures were made. This was done to prevent the loss of moisture by evaporation from the surface of the sample during the heating, and thereby to ensure that the moisture content of the sample was constant for the complete series of observations. As a check on this point, some of the observations at 20° C. were repeated after the complete series of measurements at the higher temperatures had been made. The results obtained agreed with the original results sufficiently closely to prove that there was practically no change of moisture content during the whole series of observations.

The values obtained for the capacity of samples at temperatures as high as 90° C. usually decreased with time, e.g. in one case by 3 per cent in an hour. This was found to be due to the development of bubbles on the surface, and there is little doubt that in this condition the samples were beginning to lose moisture. The readings at high temperatures were therefore taken as quickly as possible, and they must be regarded as subject to larger errors than those at low temperatures. The bubbles formed in this way must have collapsed on cooling, since the capacity returned to its original value.

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* H. F. CHURCH and H. A. DAYNES: *Institution of the Rubber Industry, Transactions of*, 1930, vol. 6, No. 1.

Two samples of varnished cloth were studied in this way, L101 and L105, those mentioned previously as showing the greatest differences in their properties in moist atmospheres.

Hopkinson's Formulæ.

Many formulæ, theoretical and empirical, have been put forward to represent the variation of dielectric properties with frequency. An account of these has been given in a previous communication.[*] Attempts were made to fit the results obtained in the present investigation to these formulæ, and although no single formula was found to represent all the results, a considerable measure of success was obtained with the formulæ first obtained by Hopkinson,[†] and afterwards by Schweidler.[‡] These formulæ rest on the following basis. If at a certain instant denoted by $t = 0$, a constant voltage V is applied to a dielectric system, an electric displacement is produced which may for convenience be arbitrarily divided into three parts:—

(*a*) An instantaneous displacement VC_0, where C_0 is the instantaneous capacity or geometrical capacity of the system.

(*b*) A displacement which takes place at a constant rate VG_0 and persists as long as the voltage is applied. This is the normal conduction current, and G_0 is the d.c. conductance of the system.

(*c*) A displacement which occurs at a rate which at any instant t may be represented by

$$i = V\beta C_0 f(t) \quad . \quad . \quad . \quad . \quad . \quad (17)$$

This is the residual charging current or absorption current. β is a constant and $f(t)$ approaches zero as t becomes infinitely great.

It is to be noted that the displacement is considered to be proportional to the applied e.m.f., i.e. the effects of simultaneously applied e.m.f.'s are additive. Hopkinson generalized this further in his Superposition Principle, which states that the effects of successively applied e.m.f.'s are also additive.

Expressing this principle mathematically

$$i_2(t) = \beta C_0 \int_{-\infty}^{t} \frac{dE(u)}{du} f(t-u)\,du \quad . \quad . \quad (18)$$

where $i_2(t)$ is the absorption current at time t produced by an applied voltage, the variations of which with time are represented by the function $E(u)$. The effects of an applied voltage of sine wave-form may be derived from this formula by putting

$$E(u) = E_0 \sin \omega u$$

and we then find that the effective capacity (C) of the system at the frequency $\omega/(2\pi)$ is given by

$$C = C_0\left[1 + \beta \int_0^{\infty} f(x) \cos \omega x \, dx\right] \quad . \quad . \quad (19)$$

and the effective conductance is given by

$$G = G_0 + \omega\beta C_0 \int_0^{\infty} f(x) \sin \omega x \, dx \quad . \quad . \quad (20)$$

The form of the function $f(t)$ is not known, but both Hopkinson and Schweidler found that $t^{-\alpha}$, where $0 < \alpha < 1$, formed a good approximation. Substituting this in the above equations, we obtain

$$C = C_0\left[1 + \beta\Gamma(1-\alpha) \sin \frac{\alpha\pi}{2}\omega^{\alpha-1}\right] = C_0 + B\omega^{\alpha-1} \quad (21)$$

$$G = G_0 + \beta C_0 \Gamma(1-\alpha) \cos \frac{\alpha\pi}{2}\omega^{\alpha} = G_0 + A\omega^{\alpha} \quad . \quad (22)$$

where

$$B/A = \tan \frac{\alpha\pi}{2} \quad . \quad . \quad . \quad . \quad (23)$$

Assuming for the moment that these equations are valid, it follows that the behaviour of any given insulating material can be represented by four constants, the dielectric constant κ_0, the d.c. conductivity σ_0, the absorption index α, and the absorption coefficient β. These constants are, of course, independent of the size of the sample under consideration. In practice κ_0 and σ_0 are calculated from the values of C_0 and G_0 respectively and the dimensions of the specimen tested. Similarly in this investigation, values of the apparent dielectric constant or permittivity κ, and a.c. conductivity σ at any frequency $\omega/(2\pi)$, were calculated from the values of C and G respectively, at that frequency. For these quantities, the above equations become

$$\kappa = \kappa_0 + b\omega^{\alpha-1} \quad . \quad . \quad . \quad . \quad (24)$$

$$\sigma = \sigma_0 + a\omega^{\alpha} \quad . \quad . \quad . \quad . \quad (25)$$

Experimental Results.

The relation between the observed values of the a.c. conductivity, σ, and the frequency $n = \omega/(2\pi)$ is shown in Figs. 10 and 11, in which the two quantities are plotted, using logarithmic scales. It has been mentioned that the measurements were made with a voltage of the order of 200 volts applied to a sample of thickness 0·2 mm. Thus the voltage gradient was of the order 10^4 volts per cm and the quantity plotted in the diagrams, $10^8\sigma$, represents the power dissipated in watts per cm cube of material under this voltage gradient. It is at once apparent that in many cases the results for a sample of material in a given condition all lie on a straight line, and therefore we may write

$$\sigma = a'n^{\alpha} \quad . \quad . \quad . \quad . \quad . \quad (26)$$

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[*] "A Critical Résumé of Recent Work on Dielectrics," *Journal I.E.E.*, 1926, vol. 64, p. 1152.

[†] J. Hopkinson: *Proceedings of the Royal Society*, 1886, vol. 41, p. 453.

[‡] E. R. v. Schweidler: *Annalen der Physik*, 1907, vol. 24, p. 717.

where a is the slope of the straight line. This means that equation (25) holds, but that the d.c. conductance σ_0 is negligibly small. It is to be noticed that this is always the case when the moisture content is small, and the temperature low, and, as may be expected, there is always a tendency to approach this law as the frequency is increased, even when the effect of σ_0 is appreciable at low frequencies.

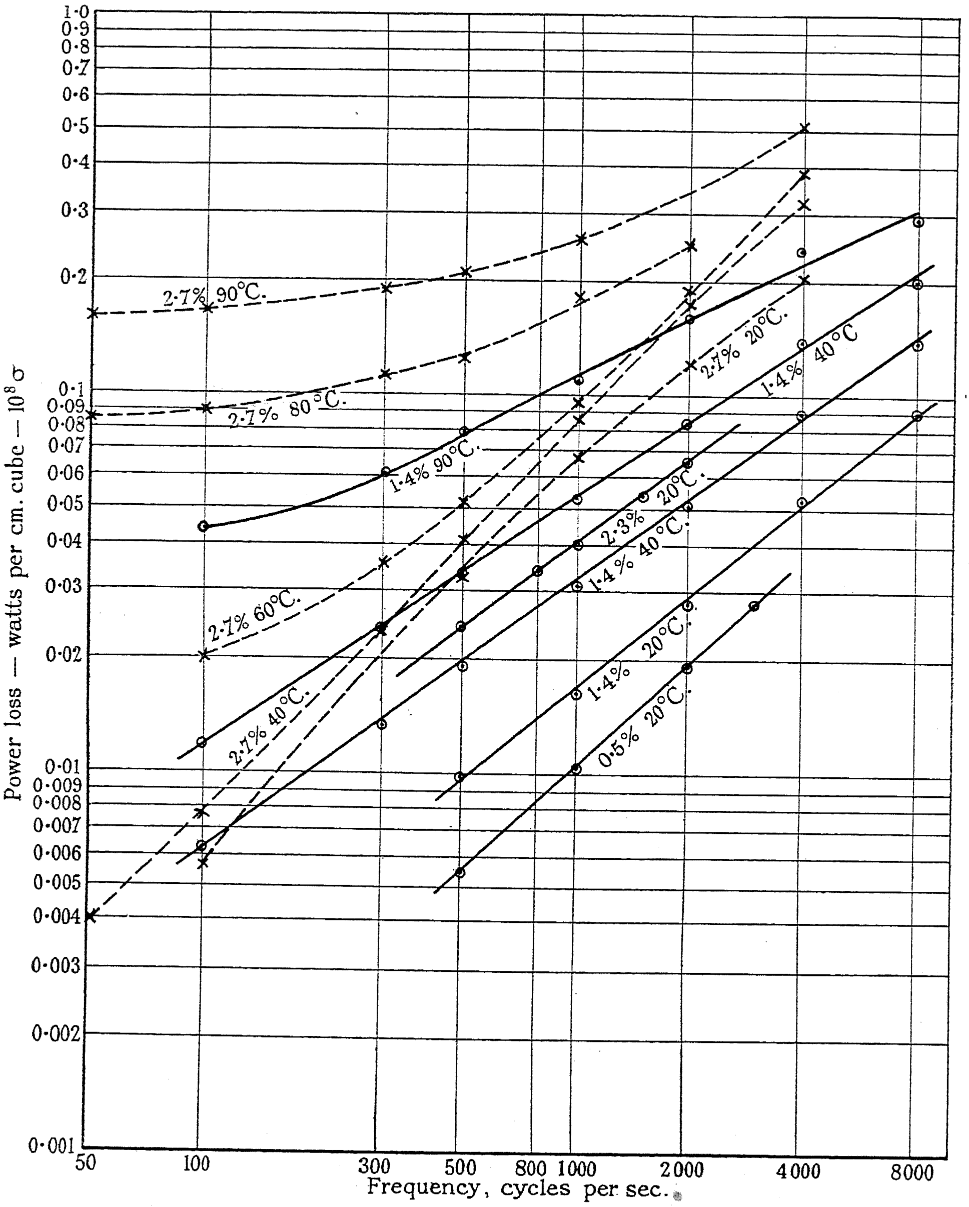

FIG. 10.—Power loss as a function of frequency. Black varnished cloth (L101) at 10^4 volts/cm.

The effect of σ_0 is to cause the line to curve upwards at the low frequency end, and when this was the case the validity of equation (25) was tested in the following manner. Writing the equation in the form

$$\sigma = \sigma_0 + a'n^a \quad . \quad . \quad . \quad . \quad . \quad (27)$$

we see that if readings of σ at the frequencies n_1, $2n_1$, $4n$, . . . 2^pn, are tabulated, and the differences between successive values of the series are noted, the general term of this series of differences should be represented by

$$\Delta = a'n_1^a(2^a - 1)2^{pa}$$

$$\log \Delta = \log \left[a'n_1^a(2^a - 1)\right] + pa \log 2 \quad . \quad (28)$$

If therefore log Δ is plotted against p, a straight line of slope $a \log 2$ should be obtained, from which a may be calculated. The validity of equation (27) may then be demonstrated by plotting σ against n^a, when a straight line is obtained, from which σ_0 and a' may be calculated. By applying this same process to the capacity readings, we may find out whether equation (24) holds good and, if so, deduce the values of the constants. This provides an independent determination of the value of α and the agreement between the two is an important piece of evidence on the question of the validity of the theory. In some cases, however, the variation of capacity was so small that an independent value for α could not be obtained with any accuracy in this way. In such cases the index $(\alpha - 1)$ was obtained from the results for σ, and then κ was plotted against $n^{\alpha-1}$. The resulting curve was usually a straight line showing that equation (24) holds good.

Another important piece of evidence is provided by equation (23). The ratio of the two coefficients B and A was found, and compared with the value of

$$\tan\frac{\alpha\pi}{2}$$

The equality of these two quantities is probably the most satisfactory test of the theory, since it involves both the capacity and conductance equations.

The various series of observations were examined in one or more of the ways indicated above, and it was found that, broadly speaking, Hopkinson's equations would represent all the results obtained for both the black and yellow cloths, except when either the moisture

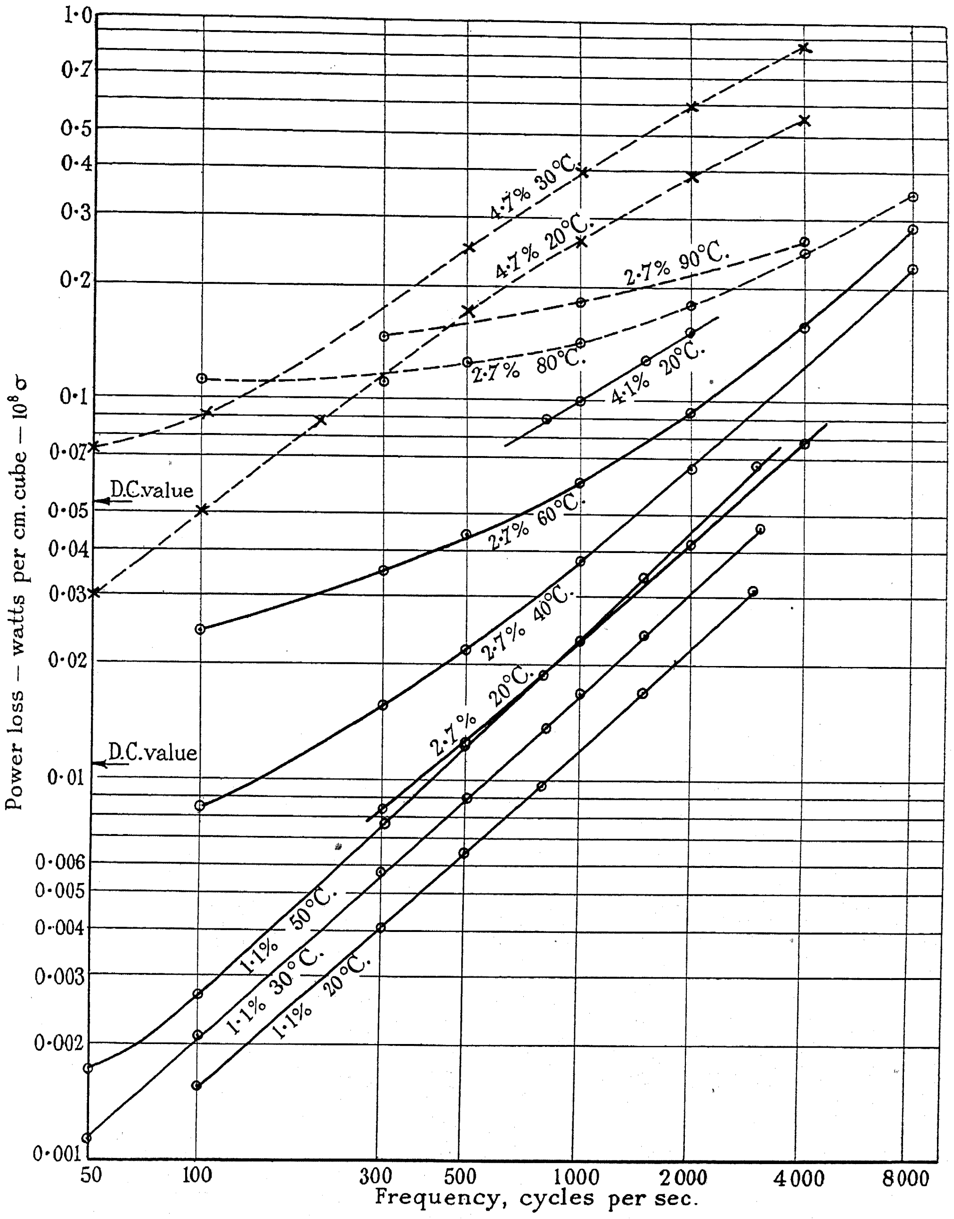

FIG. 11.—Power loss as a function of frequency. Yellow varnished cloth (L105) at 10^4 volts/cm.

content or the temperature of the material was very high. Thus the equations will fit all the curves in Figs. 10 and 11 except those shown dotted, and it may be observed that these are the curves for samples of high moisture content (samples in moisture equilibrium with an atmosphere of relative humidity 75 per cent at 20° C.) together with the curves for samples of moderately high moisture content at the highest temperatures (80° and 90° C.). Sample L101 at 90° C. with a moisture content of 1·4 per cent (corresponding to 25 per cent relative humidity at 20° C.) probably represents a limiting case. The values of power loss were found to be represented by an equation of the form of (22), but the corresponding capacity equation (21) would not represent the observed results. It should be noted that in Figs. 10 and 11 the observations made of samples of high moisture content at low temperatures lie on curves which are concave to the frequency axis, and this fact alone is quite sufficient to prove that equation (22) cannot be applied to such cases.

TABLE 2.

Comparative Values of the Ratio B/A and tan $\frac{a\pi}{2}$.

Sample	Temperature, °C.	Moisture content	B/A	$\tan\frac{a\pi}{2}$
		per cent		
Black:				
L101	20	0·5	8·1	8·1
L101	20	1·4	3·25	3·1
L101	30	1·4	2·9	2·9
L101	40	1·4	2·26	2·20
L101	60	1·4	1·69	1·69
L101	19	2·3	2·24	2·12
Yellow:				
L105	20	1·1	5·4	5·6
L105	30	1·1	6·45	6·3
L105	40	1·1	7·1	7·1
L105	50	1·1	7·5	8·1
L105	20	2·7	4·5	4·9
L105	40	2·7	3·1	3·2
L105	60	2·7	4·8	4·5
L105	19	4·1	1·38	1·41

In order to demonstrate the validity of the equations, Table 2 has been drawn up. For each series of observations, the index a and coefficient A were calculated from the conductance results, and the coefficient B was calculated from the capacity results. The ratio B/A was then calculated and compared with

$$\tan\frac{a\pi}{2}$$

These two quantities are shown in adjacent columns in Table 2, and the agreement between them shows that the observations of both capacity and power loss must in all the cases tabulated satisfy equations (21) and (22).

The Fundamental Constants.

It has been pointed out that if equations (21) and (22) are satisfied, the properties of a dielectric may be completely represented by the four fundamental constants κ_0, σ_0, a, and β. The values of these constants were calculated for each of the cases in which the equations were found to hold good. They are shown in Table 3. In the cases where no value of σ_0 is given, this quantity was negligibly small compared with the a.c. conductivity.

TABLE 3.

Values of the Four Fundamental Constants for Various Samples of Varnished Cloth.

Sample	Temperature, °C.	Moisture content,	κ_0	a	β	σ_0
		per cent				
L101 (black)	20	0·5	3·26	0·923	0·073	
	20	1·4	4·02	0·80	0·30	
	30	1·4	4·12	0·79	0·45	
	40	1·4	3·91	0·73	1·09	
	60	1·4	5·05	0·66	2·76	
	90	1·4	4·85	0·535	22·8	$1·4 \times 10^{-10}$
	19	2·3	4·46	0·72	1·30	
L105 (yellow)	20	1·1	3·90	0·885	0·103	
	30	1·1	3·76	0·897	0·133	
	40	1·1	3·55	0·91	0·159	
	50	1·1	3·52	0·92	0·165	$0·02 \times 10^{-10}$
	20	2·7	4·43	0·87	0·206	
	40	2·7	5·60	0·81	0·479	$0·36 \times 10^{-10}$
	60	2·7	4·67	0·86	3·03	$1·6 \times 10^{-10}$
	19	4·1	5·82	0·61	7·41	

The changes in the absorption index a with changing conditions are comparatively small. It decreases as the moisture content increases. For the black material it also decreases as the temperature increases, but for the yellow material it appears to be practically independent of the temperature.

The corresponding changes in the absorption coefficient β are very large except when the moisture content is very small. In considering the power losses in alternating fields, β is the most important single constant of the material, and it is obvious from Table 3 that it is determined almost entirely by the moisture content and the temperature. When the moisture content is very small (say less than 1 per cent), β is of the order of 0·1 and only increases slowly with rise of temperature, but as the moisture content increases, β increases approximately exponentially with both rise of temperature and moisture content.

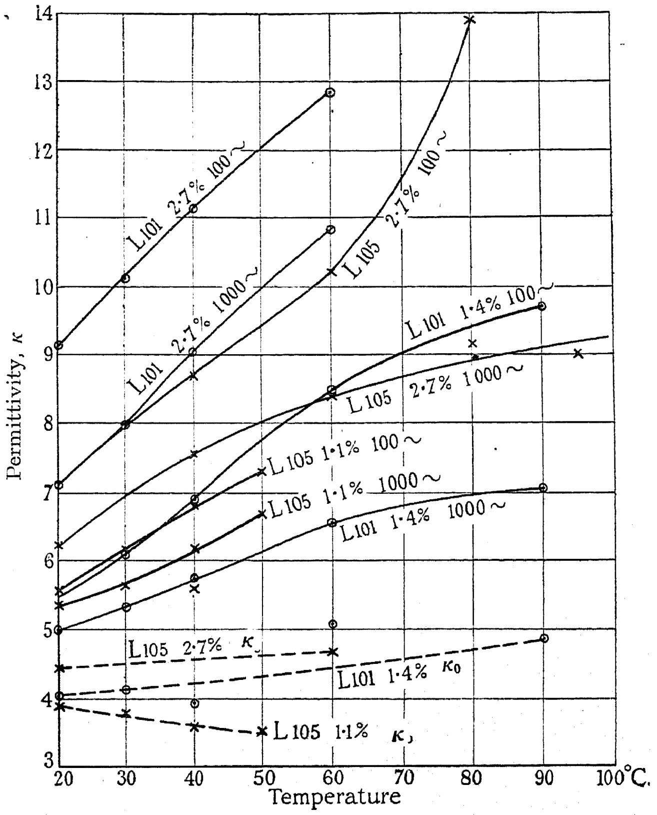

FIG. 12.—Permittivity as a function of temperature for various moisture contents and frequencies.

The constant κ_0 may be regarded as the true dielectric constant of the material. It is considerably smaller than the values of permittivity obtained by measurements at telephonic or power frequencies, and also varies much less than the permittivity with changes of temperature and moisture content. A selection of typical permittivity curves is shown in Fig. 12, and on the same diagram the corresponding values of κ_0 are also shown. This diagram shows clearly that the permittivity increases rapidly with increase of temperature, but κ_0 changes comparatively slightly. It appears to be not improbable that the temperature coefficient of κ_0 is negative (and in this connection it is interesting to note that the dielectric constant of water is known to have a negative temperature coefficient), but the accuracy obtainable by means of the necessarily indirect method used to determine κ_0 is hardly sufficient to give conclusive evidence on this point. It is, however, sufficient to show that the electrical displacement represented by κ_0, and that represented by $\kappa - \kappa_0$ (the absorption or residual component), are of the same order of magnitude in these experiments, but that they are affected in very different ways by a rise of temperature. It is, therefore, highly probable that the physical processes underlying the two components of the displacement are entirely different.

Another interesting point is brought out by plotting values of κ_0 for samples at 20° C., against the corresponding values of moisture content. This is done in Fig. 8, which shows that κ_0 is practically the same for both black and yellow varnished cloth, but that it varies linearly with the moisture content. This relation lends considerable support to the idea that κ_0 represents the actual dielectric constant of the material.

Direct-Current Experiments.

Equations (21) and (22) which have been shown to represent the behaviour of the material in certain conditions, when it is subjected to alternating voltage of sine wave-form, were deduced from an empirical equation, which was found by Hopkinson (and several later workers) to represent the residual charging current which flows when a uni-directional voltage is applied to a dielectric. It therefore seemed desirable to make measurements under steady voltage conditions in order to find out whether the current flowing agreed with that calculated from the fundamental constants which were obtained from the a.c. results.

Material in a dry condition (sample L101 in equilibrium with an atmosphere of relative humidity 10 per cent at 20° C.) was used for these measurements, as it had been found to obey Hopkinson's equations for a.c. with considerable accuracy. When the sample and the applied voltage were the same as for the a.c. observations, the currents flowing were found to be too small to measure by means of an ordinary galvanometer. A quadrant electrometer method was therefore used. It has been fully described in a previous paper,* to which the reader is referred for details.

The fundamental equation

$$i = V\beta C_0 t^{-a} \quad . \quad . \quad . \quad . \quad (29)$$

gives the residual charging or absorption current only. The true leakage current is always added to this when a voltage is applied to the sample, and in order to avoid difficulties due to leakage the current first measured was that obtained when the sample was discharged, after having been charged at a constant voltage for a very long time. During the discharge the two electrodes were always at the same potential and there was therefore no leakage current. Further, by the Superposition Principle, the residual discharging current after a very long charge is also given by equation (29) if t is measured from the instant at which the discharge begins.

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* *Journal of Scientific Instruments*, 1926, vol. 3, p. 297.

The sample was first short-circuited for some time, in order to allow it to become completely discharged. It was then charged with a constant voltage (V) for about 48 hours. At an instant denoted by $t = 0$, the voltage was reduced to zero, and the discharge current (i) was then measured at intervals during the next two days. The temperature was, of course, kept constant throughout the experiment. The results are shown in Fig. 13, in which the ratio i/V is plotted against time using logarithmic scales. The straight line (1) in this diagram represents the value of i/V obtained by calculation from the a.c. results. The continuous curve (2) represents the observed points. It is at once obvious that for values of t greater than 1 minute, the absorption current i does not obey the simple empirical law (29), which has been used to explain the a.c. results. The observed values of the current are very much larger than the calculated values in this region, and their variation with time follows no very simple law.

The next point to investigate was whether the calculated and observed curves approach one another as t becomes smaller. Hopkinson* and various subsequent observers have made observations of charging current for values of t as small as 0·0001 second. Such methods require special apparatus, and as this was not available, the plan of measuring the time integral of i between the limits $t = 0$ and $t = 0{\cdot}5$ second was adopted. This is equivalent to a measurement of the apparent capacity of the sample after a time of charge of 0·5 second, which was the smallest time for which a reliable reading could be obtained with the quadrant electrometer used. Details of the measurement of this quantity by means of the electrometer are also given in the paper previously referred to. The value obtained for the capacity of the sample was 1 100 micro-microfarads. The value obtained by calculation from the fundamental constants was

$$C = C_0 + \int_0^{0\cdot 5} \beta C_0 t^{-\alpha} dt = 1\,060 \times 10^{-12} \text{ farads.}$$

This agreement must be regarded as very satisfactory, especially in view of the large differences between the capacity with 0·5 second charge (1 100 $\mu\mu$F), the capacity measured at 1 000 cycles (820 $\mu\mu$F), and the instantaneous or true capacity C_0 (560 $\mu\mu$F); the probable errors of the various measurements and calculations involved in the comparison are quite sufficient to account for the discrepancy, and we may conclude that both the d.c. and a.c. observations are consistent with the Hopkinson theory provided that the d.c. observations are obtained for periods of charge of the order of 0·1 second and less.

The complete curve for the absorption current must take a form something like the curve of Fig. 13; as t becomes smaller the observed curve (2) must gradually approach the calculated curve (1).

It seems highly probable that the physical processes involved in the d.c. observations for times of charge of 1 minute and over play very little part in the determination of the losses in alternating fields of ordinary frequencies, for the charging current of the sample, after applying a steady voltage for 1 minute, corresponds to a conductance of only 10^{-11} mho, whereas the a.c. conductance was of the order 10^{-7} mho, i.e. 10 thousand times greater. In spite of this difference, the total electrical displacement represented by the curve (2), of Fig. 13 is much greater than that occurring during the a.c. observations. If we represent the displacement in the two cases by the equivalent specific inductive capacity, we obtain a value of about 700 for the d.c. curve (2), as against the value of about 5 for the a.c. observations. One may reasonably infer that the direct current, after a charge of 1 minute, is carried by ions of low mobility which are able to move through comparatively long distances, whereas the alternating current is carried by ions of high mobility, which move through much shorter distances.

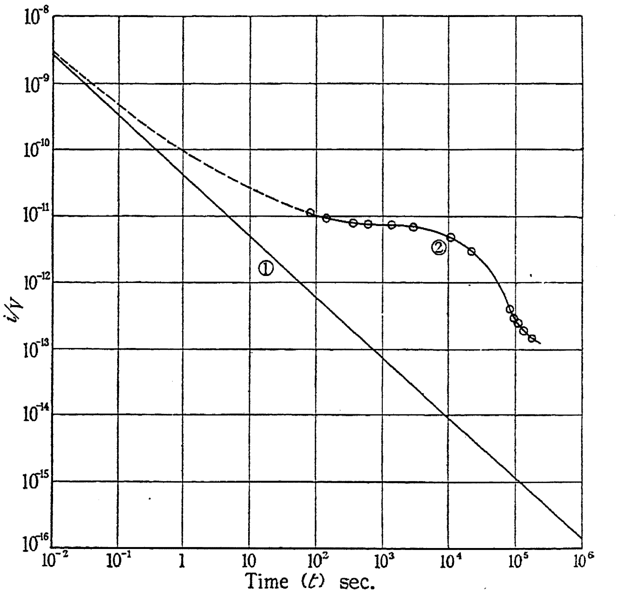

FIG. 13.—The variation with time of absorption current i, produced by the constant voltage v, observations taken on discharge.

VI. THE VARIATION OF POWER LOSS AND POWER FACTOR WITH TEMPERATURE.

Power Loss.

Curves showing the variation of power loss with changes of temperature in the range 20 to 90° C. are shown in Fig. 14, in which power loss is plotted on a logarithmic scale against temperature on a linear scale. Many of the curves approximate to straight lines, which means that there is a general tendency for the power loss to increase exponentially with rise of temperature, but that the actual rate of change depends chiefly on the moisture content of the material. Thus the black cloth L101, conditioned in an atmosphere of 75 per cent humidity at 20° C., behaves very similarly to the yellow cloth L105, conditioned in an atmosphere of 25 per cent humidity at 20° C., which is explained by the fact that under these conditions the two samples contain about the same amount of water. The temperature coefficient of the power loss

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* J. HOPKINSON, *loc. cit.*

$$\left(\frac{d\sigma}{d\theta}\Big/\sigma\right)$$

is generally of the order of 3 per cent per 1 deg. C., but it is usually greater the lower the frequency, and when the frequency is low and the moisture content high, its value may be more than double this amount. This feature of the curves suggests that the temperature coefficient of the d.c. conductivity is much greater than the a.c. value, and this is borne out by the d.c. observations that are available. See, for example, the d.c. values given on Fig. 11. Roughly speaking, the results may be summarized by the statement that the power losses increase exponentially with rise of temperature, the temperature coefficient being 3 per cent for the a.c. losses and 12 per cent for the d.c. losses.

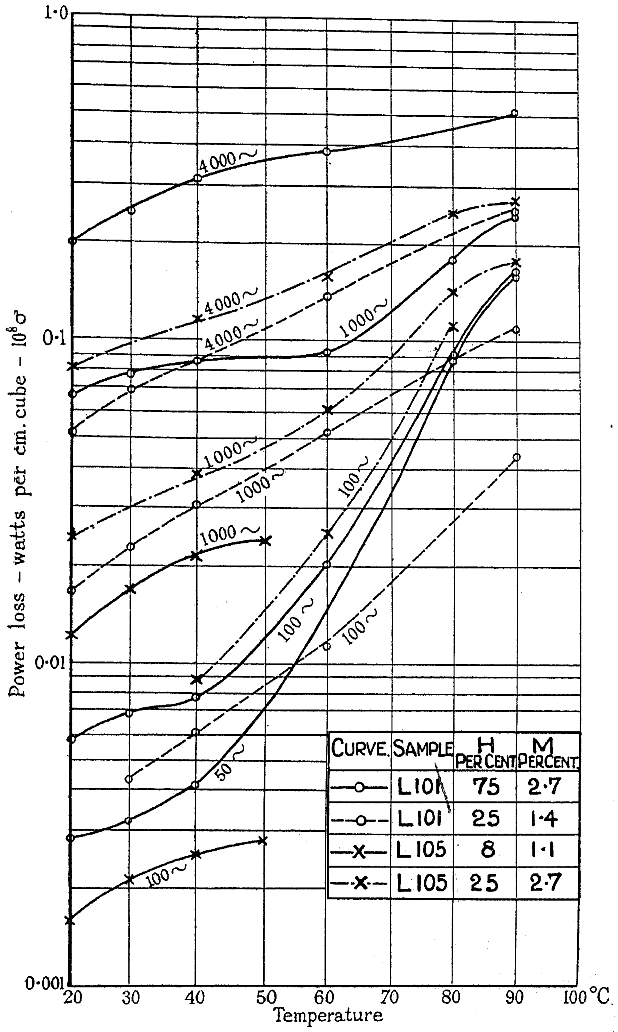

FIG. 14.—Variation of power loss with temperature.

Power Factor.

The variation of the power factor with temperature for a number of typical cases is shown in Fig. 15. It is interesting to note that values as high as 97 per cent were measured. The material was still stable under these conditions, though the sample must be regarded as an electrolytic resistance rather than a condenser. The value of the permittivity at this point was 29·3. It will be noticed that the shape of the power-factor curve is determined by the moisture content, and that it may possess a maximum and also a minimum point. The corresponding permittivity curves are shown in Fig. 12.

VII. CONCLUSIONS: THEORIES.

Conclusions.

The following conclusions may be drawn from this investigation:—

(*a*) When varnished cloth is subjected to an alternating voltage gradient less than a certain critical value, the power dissipated in the material is proportional to the square of the applied voltage, and the permittivity and power factor are independent of the voltage. The critical voltage gradient is not less than 2 kV/mm.

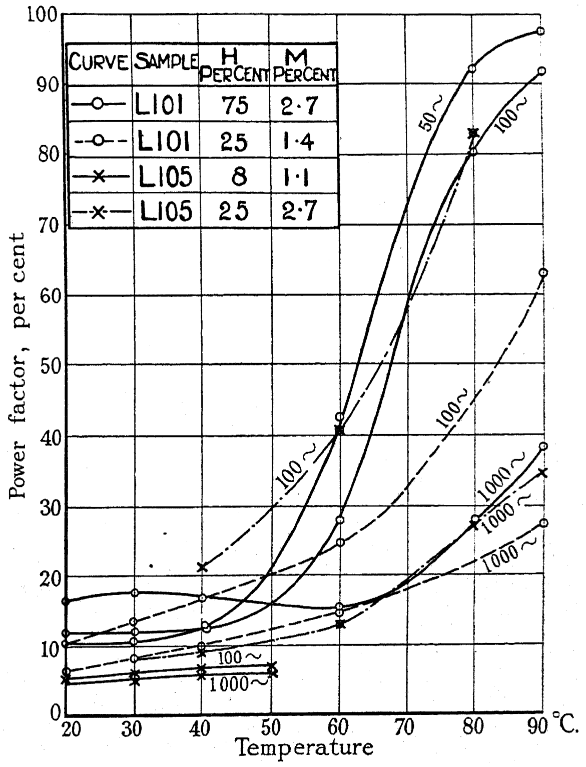

FIG. 15.—Power factor as a function of temperature.

(*b*) The power dissipated under such conditions in the frequency range 50 to 8 000 cycles may be entirely accounted for by the phenomena of dielectric "absorption" and normal conduction, and there is no discrepancy between direct- and alternating-current observations, provided the d.c. observations are made after times of charge or "electrification" of the same order as the periodic time of the alternating current.

(*c*) The properties of the material are very largely determined by its moisture content.

(*d*) The properties of a sample of varnished cloth may be represented by the following equations, over a wide range of conditions.

For the variation of power loss with frequency

$$W = V^2[G_0 + A\omega^{\alpha}]$$

For the variation of capacity with frequency

$$C = C_0 + B\omega^{\alpha-1}$$

For the variation of direct current with time

$$I = V[G_0 + \beta C_0 t^{-\alpha}]$$

The first and second of these equations were deduced from the third by Hopkinson by an application of the Superposition Principle, which states that the effects of successively applied voltage increments are similar and additive. The only samples which did not obey the first and second equations were those of very high moisture content. The third equation only holds for short times of electrification.

(*e*) Direct-current observations made with times of electrification of 1 minute and over are not consistent with the above equations. Such currents are small compared with those for which the equations were found to hold, but the total electric displacement caused by them is very large. It is concluded that the direct current after a charge of 1 minute is carried by ions of low mobility which are able to move through comparatively long distances, whereas the alternating current is carried by ions of high mobility which move through much shorter distances.

(*f*) Within the range of conditions for which the above equations hold, the properties of any sample of the material may be completely represented by the four fundamental constants: κ_0 the dielectric constant (calculated from C_0), σ_0 the d.c. conductivity, α and β the absorption constants. These quantities are affected to very different extents by a rise of temperature, and it is concluded that the physical processes which they represent are essentially different.

(*g*) The power loss increases with rise of temperature, roughly exponentially. The rate of increase is of the order 3 per cent per 1 deg. C. and there is some evidence that it is greater for the loss due to normal conduction than that due to absorption, especially when the moisture content is high. When the moisture content is very low, the power loss is much smaller and increases less rapidly with rise of temperature.

Theories.

It is probable that the physical process represented by κ_0, the "instantaneous" dielectric constant, is sufficiently accounted for by the electron theory of dielectrics. The electrical displacement involved is the displacement of electrons within the atoms or molecules, against the action of restoring forces binding them to the positive nuclei. This force is "elastic" in character, i.e. it is independent of the rate of change of the displacement, and therefore such displacements are accompanied by no loss of power. The smallness of the temperature coefficient found for κ_0 is quite consistent with this theory, and may be regarded as supporting its application to these experiments.

The direct-current conductivity σ_0 might possibly be considered as representing the convection of free electrons as in a metal, or free ions as in an electrolyte. In the case of free electrons the motion is impeded by thermal agitation, and in the case of ions by a force of the nature of the viscosity of the medium in which the motion occurs. In either case power is dissipated at a constant rate for any given voltage. The fact that σ_0 was found to increase rapidly with rise of temperature is strong evidence in support of the conclusion that ions were the carriers of the conduction current in the materials investigated, the increased conductivity at high temperatures being due to a diminution of the forces of viscosity opposing their motion.

The absorption current remains to be considered, and it is to be remembered that in most of the samples this was responsible for the greater part of the power dissipation. Several theories of dielectric absorption have been described in a previous paper,[*] and in addition to these there are three theories of a somewhat similar nature proposed by Sinelnikov and Walther,[†] the author,[‡] and Murphy and Lowry.[§] Each of these theories assumes that the absorption current is carried by ions, and that its decay with time is caused by accumulations of these ions at certain surfaces of discontinuity in the material. Such accumulations set up polarization e.m.f.'s which oppose the flow of current. These three theories only differ from one another and from Maxwell's theory in that they assume different distributions for the surfaces of discontinuity, which may be the surfaces separating the various components of an agglomerate (Maxwell), the surfaces of the material in contact with the electrodes (Hartshorn, Sinelnikov and Walther), or internal surfaces peculiar to the structure of the materials (Murphy and Lowry). The equations resulting from these assumptions are all of the same type and it is therefore difficult to distinguish between them in their application to investigations of power loss. An important theory of a fundamentally different character is Debye's dipole[¶] theory, which assumes that the molecules of some materials are not symmetrical, and that they therefore possess a permanent electric moment. When an electric field is applied to such materials it tends to rotate the molecules so as to bring their axes into line with the field, and if the molecules are free to rotate, they assume a definite orientation which constitutes a polarization of the material. The specific inductive capacity of the material is, therefore, increased by such orientation of polar molecules. Since the forces of thermal agitation oppose any definite orientation of the molecules, and these forces increase with rise of temperature, the specific inductive capacity of such material must decrease with rise of temperature. In this way the rapid decrease in the specific inductive capacity of water, alcohol, and other liquids with rise of temperature has been explained.

Now it is probable that the rotation of molecules of liquids and solids must be regarded as opposed by frictional forces depending on the viscosity of the material, and the effect of these forces will be to retard the polarization due to the polar molecules and thereby give rise to the phenomena of dielectric absorption and power loss in alternating fields. The application of this theory to the type of measurement now under discussion has been considered by S. Whitehead,* who has given equations and curves showing the forms of the functions representing the variation of the absorption current with time, and the variations of permittivity and power factor with frequency. An examination of these curves shows that they are of exactly the same type as those given by the theories previously mentioned, and it is apparent that these functions of time and frequency will be common to all theories in which the displacement of the electric carrier (*a*) is proportional to force producing it, (*b*) gives rise to a back e.m.f. proportional to the displacement, (*c*) is opposed by a frictional force proportional to the velocity of the carrier. Thus in attempting to find out the nature of the process, the variation of the properties with temperature and voltage will also be of fundamental importance.

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[*] Ref. L/T14, *Journal I.E.E.*, 1926, vol. 64, p. 1152.

[†] A. Joffé: "The Physics of Crystals," McGraw-Hill, 1928.

[‡] L. Hartshorn: *Proceedings of the Physical Society*, 1925, vol. 37, p. 215.

[§] E. J. Murphy and H. H. Lowry: *Journal of Physical Chemistry*, 1930, vol. 34, p. 598.

[¶] P. Debye: *Physikalische Zeitschrift*, 1912, vol. 13, p. 97.

The present investigation has shown that the absorption current in varnished cloth increases rapidly with rise of temperature, and we can only deduce from this that it is probably produced by the motion of electric carriers, which may be ions or polar molecules, or even groups of molecules with polar properties, against the action of a frictional force such as that due to the viscosity of the medium. We have also found that the displacement of these electric carriers must conform to the Superposition Principle, and that the expression for the decay of the current with time must, for short time intervals, approximate to the form

$$t^{-\alpha}$$

Now all the theories which have been mentioned describe an electric displacement which conforms to the Superposition Principle, but none of them gives a simple explanation of the function

$$t^{-\alpha}$$

K. W. Wagner's* extension of Maxwell's theory provides a statistical explanation of this function for composite materials containing constituents of widely different properties, and as it is known that varnished cloth is a complex mixture of several substances, the assumptions of the theory would appear to be well founded. It must, however, be realized that the function

$$t^{-\alpha}$$

is only explained as the sum of many terms of exponential form, and that Wagner's analysis can equally well be applied to the other theories mentioned. It is merely necessary to assume that the electric carriers, whether ions or polar molecules, are not all of the same kind, or that their motion is retarded by different frictional forces, due to differences in size, etc. In this way the expression for the absorption current may be shown to consist of the sum of a number of exponential terms, or terms of approximately this form, one for each kind of carrier, and a distribution of such terms may be found, such that their sum gives the observed curve. The evidence as to the nature of the process is therefore not conclusive, although the general nature of the laws governing it has been established.

The measurements recorded in this paper were carried out for the British Electrical and Allied Industries Research Association at the National Physical Laboratory between 1922 and 1929. The writer wishes to thank several of his present and former colleagues on the staff of the Laboratory, particularly Mr. D. A. Oliver and Mr. E. Rushton, for their help in the experimental work.

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* S. Whitehead: Ref. L/T34, *Philosophical Magazine*, 1930, ser. 7, vol. 9, p. 865.

* K. W. Wagner: *Archiv für Elektrotechnik*, 1914, vol. 2, p. 371; and *Journal I.E.E.*, 1926, vol. 64, p. 1152.

DISCUSSION ON

"RECENT PROGRESS IN LARGE TRANSFORMERS"* AND "THE APPLICATION OF THE INDUCTION VOLTAGE REGULATOR."†

MERSEY AND NORTH WALES (LIVERPOOL) CENTRE, AT LIVERPOOL, 2ND NOVEMBER, 1931

Mr. P. J. Robinson: In my opinion Mr. Charley hardly does justice to British transformer manufacturers either in Schedules I and II or in the body of his paper. Referring to Schedule I, the two items at the top of the list appear to be auto-transformers of 2/1 ratio, so that the equivalent straight kVA ratings are half the values given. If this correction is made, the first and second places in the Schedule are each taken by a British manufacturer, whilst two out of the next four items are also British. It is of interest that the 75 000-kVA transformers are being installed at the "grid" substation in Liverpool. These units have a self-cooled rating of 50 000 kVA and are the largest self-cooled transformers in the world. It should also be noted that a British manufacturer shares the second place in Schedule II. In dealing with the inter-turn insulation in transformer windings, the author refers to a proposed British Standard Specification. I notice that the insulation called for in the new specification is appreciably less than in present standard practice, as shown by Table 2. Unless it is agreed that transformers as at present constructed are much stronger than is necessary as regards inter-turn insulation, I should like to know on what grounds the author expects better service from a specification incorporating the new values. In the section dealing with core construction the author describes the 5-limb core for 3-phase units, and makes it appear that this construction is very advantageous as compared with the normal 3-limb construction. Certain advantages of the 5-limb core are given, but there must surely be serious disadvantages, otherwise manufacturers would adopt the 5-limb method for small and medium-size transformers. It seems to me significant that no manufacturer uses the 5-limb construction unless he is compelled to do so by difficulties of transport and interleaving.

Mr. L. Breach: I take exception to Mr. Charley's remark that the parallel-winding scheme for tap-changing has become nearly obsolete, in so far as I understand that many of the "grid" transformers are arranged in this way. These units were presumably put forward as an example to the whole world of what British manufacturers could produce, and it would be a grave admission on the manufacturers' part to state that they are now obsolete. Also, we have just put into commission four 12 500-kVA transformers each with a parallel-winding arrangement of tap-changing, and we do not consider that this plant is obsolete. We have auto-transformers and parallel-winding arrangement on our system, and both have proved satisfactory. Each requires careful attention to ensure that the tap-changing gear operates satisfactorily and also that it completes its operation. I do not agree with the statement that the concrete type of reactor is unpopular. I should imagine that the oil-immersed reactor has several grave disadvantages, the first being the increased danger due to oil fires. There is already enough risk of fire in a switch room, without its being added to in the shape of reactors which may develop a large amount of heat under fault conditions. If the concrete type are installed with due regard to their proximity to ironwork, there would appear to be little difference in the floor space occupied. Aluminium doors and screens for use with the concrete reactors are, of course, quite common and are not expensive, and allow of closer spacing of the reactors. As there will undoubtedly be more heat to be dissipated in the oil type in view of the increased losses which are admitted by the author, it is quite possible that the floor space required by them may be even greater than in the case of the air-cooled type. Another difficulty which presents itself is the question of ventilation, since it is no easy matter to get rid of the heat from the air-cooled form; and this difficulty will be increased in the oil type. In the sketch of the reactor (Fig. 17) the rings appear to be attached directly to the tank. I should be glad if the author would state whether this is so, or whether they are insulated; in any case it seems to me that local heating would be set up on the sides of the tank, which would cause stresses in the tank itself. I have no comments to make as regards the actual size of the transformers manufactured, apart from the observation that there will be considerable trouble if a fault develops in a large transformer, as it would not appear possible always to have a complete stand-by unit available. While the risk of a fault in the winding itself is not great, the small details are just as essential to the safe working of the transformer and are perhaps more likely to lead to trouble. Some time ago a temperature alarm operated in one of our stations, and as the oil temperature was excessive the transformer in question, which was rated at 10 000 kVA, had to be taken out of commission. Investigation showed that a bolt holding the current transformer associated with the temperature indication system had become slack and had fallen on to the core. This set up arcing between the core and the bolt (which was earthed) and created a high temperature locally, fusing the core and the bolt but causing no further damage. The transformer was in commission again within a few hours. This example goes to show that a large transformer which is not faulty in itself may be put out of commission through some trivial fault. It is of interest to know that we have in Liverpool 500 000 kVA of transformers rated at 4 000 kVA and over, the largest being of 35 700 kVA. In his comparison of shell- and core-type transformers Mr. Charley fails to emphasize that the core type has a distinct advantage in that far less time is required to open up its windings. An interesting point not referred to in the paper is the question of safeguarding the oil and water flow in the forced oil-cooled type of transformer; it is essential for an alarm to be operated should either the oil or water cease to flow, and up to the present we have not come across a satisfactory indicator for the water system. The oil does not present so great a difficulty as the water, electrolysis having been the chief difficulty associated with the latter. Presumably some kind of indicator is installed in the auxiliary cooling system of the larger naturally-cooled transformers referred to in the paper. I would urge manufacturers to provide transformers that do not leak. The author suggests that tanks should be filled with nitrogen during transport, but I think that some difficulty will be found in keeping them gas-tight; up to the present we have not even found such tanks to be oil-tight. Practically every transformer provided has to have some attention after it has been put into commission and the oil has been heated and cooled. This may not at first appear to be a great difficulty, but when one considers what it means to have to disconnect a large bank of transformers and also the cable supplying it, one realizes that it is a serious matter to have the makers constantly trying to stop oil-leaks. We have suffered a great deal in this respect. The Buchholz protective gear is of no use unless there is a conservator on the transformer. There are, however, a great many transformers in commission without conservators. I agree that the Buchholz device is an excellent piece of apparatus provided that there are no gas locks prior to the relay itself. I agree with Mr. Charley regarding over-severe tests on transformers before these are sent out, as such tests may weaken the transformer so much that it may fail later under far less exacting conditions. Has the author found a way of protecting a star/star-connected transformer against failure of the tertiary winding? I have in mind a case of a transformer being set on fire through an outside fault not being cleared, and causing the tertiary winding to burn out. Has he any ideas regarding protection from fire, a very serious matter in a large transformer, especially if it is installed in a building? We are told that fires are impossible, but they have occurred and will occur again, and the manufacturers should be in a position to offer some solution of this problem. Although the fire itself may not be a serious danger, there may be a grave risk of the burning oil spreading.

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* Paper by Mr. R. M. CHARLEY (see vol. 69, p. 1189).

† Paper by Mr. W. E. M. AYRES (see vol. 69, p. 1208).

Prof. F. J. Teago: The introduction of the shielded transformer is a very recent and interesting event, and in this connection Mr. Charley's statement (page 1198) that the claims of the inventors of non-resonating transformers are not generally accepted as true, leads me to make the following observations.

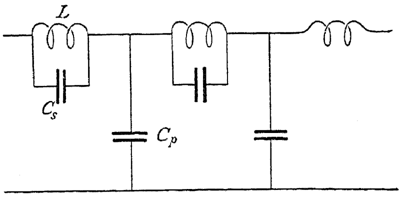

Fig. D.

Fig. D is a simple representation of a transformer, in which the resistance of the coils is neglected and where

C_s = self-capacitance of the windings,
C_p = capacitance between coils and earth,
L = inductance of coils,
$\omega = 2\pi f$.

The equivalent impedance of L and C_s is

$$\omega L/(1 - \omega^2 C_s L)$$

and when the frequency of the disturbance is greater than that given by

$$1 - \omega^2 L C_s = 0 \quad . \quad . \quad . \quad . \quad . \quad (1)$$

then the impedance is negative and the transformer circuits behave as shown by Fig. E, i.e. like a string of insulators. If the frequency is less than that given by (1), the impedance is positive and the transformer behaves like a transmission line, as shown by Fig. F. It is known that, under normal working conditions, in the case of an unshielded string of insulators about 25 per cent of the total p.d. is sustained by the line disc, and that in the case of a suitably shielded string the distribution of the p.d. is uniform. For a suitably shielded transformer behaving as shown by Fig. E, the normal p.d. distribution over the coils will also be uniform, but what will happen when a high-frequency steep-fronted voltage wave is impressed on the circuit? If the ohmic resistance of the links connecting the C_s condensers together is negligibly small, the total p.d.

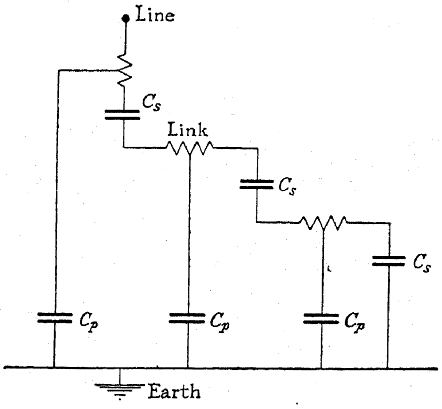

Fig. E.

across the circuit will rise, but its distribution will remain uniform during the whole of the time interval under consideration. This state of affairs probably obtains in the case of a string of insulators, with the result that possibly no disc is stressed to its breakdown limit. In the case of a transformer, however, the links between the C_s condensers are the coils and these may interpose an appreciable resistance into the C_p condenser paths, so that a time-interval is required to charge the system of C_p condensers. This means that, initially, the whole of the extra p.d. is across the end coils and that an appreciable time-interval must elapse before its distribution across all the coils is uniform, with the result that insulation breakdown may take place on the end coils in spite of the presence of the shield. The fact that the C_s condensers take time to charge is unimportant; the trouble is due to the resistance in series with the C_p condensers. For an insulator string this is very low, but it may be appreciable for a transformer. While this may be objected to on the grounds that the required time-interval is very short, the whole time-interval under consideration is possibly of the order of 0·5 micro-second, so that the charging interval is an appreciable part of the whole time. In a shielded insulator-string the ohmic resistance is probably low enough to warrant the assumption that no sensible fraction of time is required to produce a uniform distribution of the p.d., but can the same be said about the transformer? If not, a shield cannot fully protect a transformer against the effect of a high-frequency steep-fronted voltage wave. The applicability of the adjective "non-oscillating" to the shielded transformer may be investigated in the following manner. At frequencies which cause the transformer to behave like the circuit shown in Fig. E no oscillations can ever occur, because no circuit can oscillate which does not contain both inductance and capacitance. Such frequencies then would cause the transformer to charge in a logarithmic manner, whether it were shielded or unshielded. Suppose, however, that a steep-fronted voltage wave of a frequency low enough to cause the transformer to behave like the circuit shown in Fig. F is impressed on the system. Under these circumstances the impressed p.d. might be regarded as a short d.c. impulse, and either or both of the circuits a and b (Fig. F) may charge in an oscillatory manner. The condition for such a charge is that

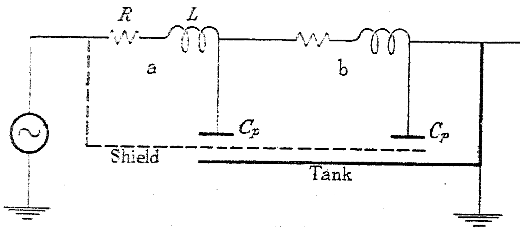

FIG. F.

$$2\sqrt{(L/C_p)} > R$$

which will obtain if R is low or if C_p is small. On the other hand, the introduction of the shield (shown dotted in Fig. F) may make C_p so large that

$$2\sqrt{(L/C_p)} < R$$

in which case the system will charge in a logarithmic manner and be non-oscillatory; but can the shield be made large enough to ensure a logarithmic charge? Supposing the system to oscillate, and putting

$$q = \sqrt{\left[(4L/C_p) - R^2\right]}$$

then the p.d. (e_1) across C_p, which is the p.d. between the transformer coil and earth, is given at a time t seconds after the application of the wave of amplitude e by

$$e_1 = e\left\{1 - \epsilon^{-Rt/2L}\left[\cos\left(\frac{qt}{2L}\right) + \frac{R}{q}\sin\left(\frac{qt}{2L}\right)\right]\right\} \quad (2)$$

As can be seen, some values of t make e_1 greater than e which may be large in itself, and it is easily appreciated that dangerously high p.d.'s may exist between the coils and earth. If C_p cannot be made large enough to render the system non-oscillatory, it will pay to keep it small in order that q may be large and e_1 small. Thus unless the shield makes C_p large enough to render the circuits non-oscillatory, it would appear to do more harm than good. It must be remembered, however, that the change from oscillatory to non-oscillatory conditions obtains when

$$R = 2\sqrt{(L/C_p)}$$

but that, provided the actual resistance is about 50 per cent of this critical value, then, although the circuit will oscillate, the oscillations will die out within about two complete periods. The equation for the current due to the disturbance is

$$I = \frac{2e}{q}\epsilon^{-Rt/(2L)}\sin\left(\frac{qt}{2L}\right) \quad . \quad . \quad . \quad . \quad (3)$$

and may be large enough to damage the windings of the transformer. Points in favour of the shield are:—
(a) To some extent it masses the capacitance and thus tends to prevent oscillations on any frequency except the fundamental, which is approximately given by

$$f = \frac{1}{2\pi}\sqrt{\left(\frac{1}{LC_p}\right)}$$

(b) When carefully proportioned, it ensures equality between the values of C_p in the various parts of the transformer, which would prevent any section from having an independent oscillation frequency. For an arcing-earth, which also tends to make the circuits behave like Fig. F, the given equations need modifying since the disturbance is harmonic, but the conclusions drawn are still applicable. The application of a shield to a transformer is not without a certain amount of danger and would probably cost more than reinforcement of the end turns; and it may not, after all, achieve its purpose. If in his reply the author can give representative values for the resistances, inductances, and capacitances of the large "grid" transformers, a more complete analysis of the problem will be made.

[The replies of Mr. Charley and Mr. Ayres to this discussion will be published later.]

NORTH-WESTERN CENTRE, AT MANCHESTER, 10TH NOVEMBER, 1931.

Mr. E. T. Norris: Referring to Mr. Ayres's paper, induction regulators have been manufactured in this country for many years. It seems strange that for purposes of feeder-voltage regulation they are not used to a great extent, especially in view of the fact that in other countries—the U.S.A., for example—automatic induction regulators are a standard feature of all low-voltage distribution substations. In that country one sees in every distribution substation not merely one or two induction regulators, but frequently rows of them, all automatically operated. Can the author explain the reason for this marked difference in the use of induction regulators for feeder-voltage variation in the two countries? There is undoubtedly a large and intense demand for automatic means of regulating distribution voltages at an economical price. The alternative solution in general use in this country is that of increasing the size of the cable or transmission line, but this is so obviously expensive that other means, such as induction regulators, variable-voltage transformers, etc., cannot be ruled out on the score of price.

Mr. F. E. Hill: I should like to refer first to the comparison between the prices of 3-phase and three single-phase transformers for the same total output. The comparison in Mr. Charley's paper is based on outputs from 3 000 kVA at 66 kV, to 6 000 kVA at 132 kV. Such transformers are of small output for the voltages in question, and the author's relative figures give an entirely erroneous impression. For instance, for an output of 60 000 kVA at 66 kV three single-phase transformers cost about 10 per cent more than one 3-phase unit, and for an output of 45 000 kVA about 10 per cent more. As regards the relative merits of the core and shell types of construction, I agree with the author that over a large field of application both types can be designed and manufactured in equally satisfactory units. It is interesting to record that one very large manufacturer who specialized in core-type construction now uses the shell construction for air-blast transformers, where ventilation problems become most acute. I would urge buyers to leave the question of type to the designer, for he knows exactly the extent of the manufacturing facilities available and, in the light of this, is able to put forward what he considers to be the most favourable proposition for his company to build. The question of repair on site plays little or no part when large units are being considered, as, if these give trouble, the transformer is almost invariably returned to the maker. With regard to the British Standard Specification for inter-turn insulation, this has been put forward after very careful scrutiny of the available data and should prove satisfactory in service. It should be remembered that the test-voltage figures given in Table 2 are a minimum, and in my opinion—at least on high-voltage windings—owing to the use of disc coils and the voltage obtained between discs, inter-turn insulation will be used which will withstand considerably higher voltages than those required by the Specification. On-load regulation of voltage has been brought to the fore in this country by the " grid " scheme. A number of on-load tap-changing equipments have been in operation for many years. For instance, a 4 000-kVA Scott-connected transformer was built by the British Westinghouse Co. 18 years ago which has booster equipment giving a ±10 per cent range of on-load regulation. The author advocates the use of the mid-point auto-transformer scheme for providing alternative tappings, which, of course, necessitates the auto-transformer being in circuit continuously on alternative tappings and not being merely used to transfer load from one main tapping to the next. Although this reduces the number of main tappings to be brought out from the winding, as reactors are inherently noisy (and for this reason alone) I consider that such a scheme will in future be looked upon with disfavour. This will become more apparent now that the evils resulting from the use of excessively high flux densities are being realized. The more rational values of flux density now being insisted on by numerous buyers will result in a great reduction in the noise from the transformers.

Mr. L. H. A. Carr: While I agree with Mr. Ayres that limit switches should be placed directly in the motor circuit (page 1210), it is frequently desirable to treat such switches as safety or emergency devices only. In this case small single-pole limit switches may be used in the contactor circuit, so arranged that the opening of the limit switch at one end does not prevent the motor from operating in the reverse direction, and the arrangement remains fully automatic so long as these switches operate. Such switches, as is well known, can be arranged to have an exceedingly small movement between "open" and "close." Behind them is placed the safety-limit switch, which cuts current off the motor entirely, or at least off two phases. If this arrangement is adopted a saving in wiring and apparatus frequently results, since it is then possible to make use of a single safety-limit switch so situated and arranged that the moving sector will open it at each end of its travel. The control of interconnectors between power stations leads to some interesting problems. If the ordinary double induction-regulator be inserted in an interconnector and arranged so that the voltage vectors of the two units of the regulator move in opposite directions, then, as is well known, the voltage is varied without any alteration in phase angle of the total voltage, the vectors opening and closing like a pair of scissors. If, however, the rotation of one unit be reversed, then, when the regulators are turned, the two voltage vectors will rotate together and give a phase-angle shift without variation in magnitude of the regulator e.m.f. This arrangement can be obtained in practice in a variety of ways. In one method, more suitable for manual control, a plain mechanical reversing gear can be fitted between the driving motor and one unit only. According to the position of the reversing gear, the motor will either produce change of magnitude of e.m.f., or change of phase of injected e.m.f. If the reversing gear has a free neutral position, the brakes must be fitted direct to the regulators. In another method differentials are used and it is possible to arrange that one motor operates for a magnitude variation, and a second motor operates for a phase variation, the functions of the two motors remaining entirely distinct. This method is the more suitable for automatic operation. Certain details of these arrangements are, like some of those mentioned by the author, the subject matter of patents held by the manufacturers. An arrangement for operating induction regulators in parallel, which differs from that described by the author, has recently been installed in this district, and is peculiar on account of the conditions demanded and the means adopted to meet those conditions. There are three regulators and the supply is obtained from a single set of busbars. On the output side either a single busbar or a split busbar may be used, and the conditions demanded were (*a*) that it should be possible to run the three regulators in parallel on to the same busbar, (*b*) that it should be possible to run regulator No. 1 on No. 1 busbar and regulators Nos. 2 and 3 on No. 2 busbar, (*c*) that in all cases the arrangement should be purely automatic, and (*d*) that either of regulators Nos. 2 or 3 should be capable of being uncoupled and operated by hand on one of the basbars, while the other was working automatically on the other busbar. The means adopted was to use two driving motors, one driving regulator No. 1, and the other driving regulators Nos. 2 and 3, each motor having its own set of automatic gear. With this arrangement the two sets worked perfectly independently, and as claw clutches and hand-operating gear were fitted to regulators Nos. 2 and 3, either of these regulators could be separated from the remainder of the system as required. In order to operate in parallel, however, it was arranged to couple the two motors together by means of a claw clutch intended to be engaged when the two sets of regulators are in the same relative position, mechanical indicators being supplied for this purpose. While it would have been possible to arrange for one motor alone to operate all the regulators, the other being allowed to trail, a difficulty would have been introduced by reason of the brakes. Consequently a change-over switch for the control gear is provided so that when operating in this condition both motors are controlled from the same set of contactors and relays, and under these circumstances the whole bank operates together. Here each regulator has limit switches in the contactor circuits, but, in addition, safety limit switches are fitted on each of the three regulators, and if by any mischance any one of these is brought into play it cuts off the supply from both the operating motors.

Mr. G. F. Sills: Mention has been made in one of the discussions on Mr. Charley's paper that these extra-high-voltage commercial transformers only recently came into being in this country. I well remember, however, being astonished when visiting some substations in Toronto, Canada, in 1910, to see in commercial service single-phase banks of 110 000-volt transformers which had been built in Canada. In passing, one might remark that when a 3-phase transformer is described as having an output of 125 000 kVA, for example, it has this output, whereas nowadays a number of very large turbines described as having a certain output may consist of three turbo sets. A deciding factor as to whether a single-phase or a 3-phase transformer shall be installed for remote sites difficult of access, is that of weight and size. This factor is important in connection with transformers required for water-power sites abroad. Does the author happen to know the reason for the extreme height of the Japanese-built transformers of which he showed a lantern slide? It has been said that one of the reasons for the nearly universal adoption of the Buchholz device on the Continent to protect transformers against damage, is the fact that the insurance companies allow a considerable rebate on transformers so fitted. This fact seems to be an exceedingly good testimonial for the device. One must remember that it gives its indication before the fault occurs, not afterwards, and so limits the damage. A 3-phase 10 000-kVA 33-kV transformer with on-load tap-changing gear costs approximately £4 500. The extra charge for the Buchholz device only amounts to approximately £40, that is, less than 1·6 per cent. This cannot be considered excessive. About 25 million kVA of transformers on the Continent alone are fitted with the Buchholz device. For this negligible sum one is not only protecting the transformer from damage, but also from the loss of revenue should the transformer be damaged and have to be repaired. In the discussion on a paper* on large transformers read before this Centre in 1919, I pointed out the advantages of the oil-expansion vessel, and the authors mentioned in their reply that the oil-expansion vessel was quite superfluous except as an accessory to the use of inferior oil. This shows that one must not be too dogmatic in one's statements, because, first, if the oil conservator enables inferior oil to be used, it must be a very good apparatus, and secondly, the oil expansion vessel is now used all over the world. There is hardly a transformer of any considerable size now supplied without one. The moral to be drawn from this is that we must not be rash in decrying the Buchholz device. The latter is also very useful for protecting the tertiary winding in the transformer. This winding, which is otherwise unprotected, is normally incapable of withstanding a short-circuit for as long a period as the main winding. As regards the question of noise, naturally if a large transformer is housed on a site hemmed in by buildings the noise is more pronounced than it would have been a few years ago in the case of a similar site, which would then have been occupied by two 1 000-kVA units. The induction density has a decided bearing on the amount of noise, and it is suggested that the induction density should not exceed 11 000 lines per cm^2. Up to comparatively recently what were then regarded as "large" transformers of the self-cooled type were supplied with 2-in. diam. round steel tubes. These in themselves were stiff. To increase the cooling it has been necessary to use banks of thin tubes of different shapes and sizes, which are welded into headers, and in these thin tubes a certain amount of vibration is set up. It is possible that some simple adjustable screw pads fixed between the bottom of the header and the floor to place the header in slight compression, might help to reduce the noise. The gilled tubes shown on two of the author's slides appear to be subject to a serious disadvantage, as the gill consists of a thin piece of metal spirally wound on a round tube, and simply depends on the tension fit. There is thus a large area for rust to attack. I am afraid that the Lancashire climate would have a serious effect on the efficiency of the cooling, as the close contact between the spiral gill and the round steel tube would rapidly deteriorate. Fig. 7 shows the auxiliary fan underneath the main bank of radiators. Some years ago it was shown that if an ordinary desk fan was placed so as to direct air under each batch of tubes the temperature-rise was considerably reduced. It has been mentioned that the general arrangement shown in Fig. 8 necessitates the transformer being under a high head of oil. As it happens, the difference in the head is only 9 ft., which is negligible. One useful advantage of the 5-limb core-type transformer which is not referred to in the paper is that the exciting currents are better balanced and the minimum of interference with the relays takes place when the transformer is switched in. With regard to transformer bushings and inter-turn insulation, it is now becoming standard practice to grade the insulation of the various parts of a transmission line. The majority of the line should be heavily insulated because of the difficulty of replacement of insulators; for a distance of, say, half a mile from a substation insulators of lower strength should be used in order that they may flash-over before the surge reaches the substation apparatus; the transformer bushings should be considerably stronger than the adjacent line insulators, and, finally, the insulation of the transformer itself should be stronger than that of the bushings. A decided advantage of the oil-immersed reactor is that it can be easily protected by means of the Buchholz device. In connection with on-load tap-changing, for hand operation the gear should be so designed that one complete turn will give a change from one tap to the next.

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* A. G. Ellis and J. I. Thompson: "Large Power Transformers," *Journal I.E.E.*, 1919, vol. 57, p. 547.

Turning to Mr. Ayres's paper, I think we are only just beginning to appreciate the difficulties which we shall be faced with if we do not give the correct voltage to the consumer. I have been informed that to get successful results from electric cooking it is necessary that the correct voltage should be applied. If the supply authorities do not ensure the correct voltage, the efforts of the British Electrical Development Association will be nullified to a large extent. Naturally, voltage trouble is much more likely to arise when bulk supply is taken, because one of the primary objects in a generating station is to keep a constant voltage on the busbars. Some automatic type of device to ensure the correct voltage at main distributing substations or bulk users' substations is becoming increasingly necessary. America has been through this phase, and I have seen photographs of substations over there where every outgoing feeder has its own induction regulator. It cannot be too highly stressed that feeder and distribution systems should be designed from an economic standpoint, and that in the majority of cases they will then include voltage-regulating apparatus. The argument that because such apparatus increases the complication of the system it therefore increases the risk of breakdown, is not borne out by experience. The control apparatus which has been shown to us on the screen has proved itself to have a remarkable degree of reliability and to require little or no periodic inspection. Most systems require voltage correction during the daily load cycle. The authority giving a bulk supply has a greater latitude than formerly. A certain authority taking bulk supply was always being troubled by voltage variations until their engineer put in an automatic induction regulator to deal with 3 000 kVA of load. When I asked him what his experience was and whether the trouble had been overcome, he replied:—" Since we installed an automatic induction regulator our bulk-supply voltage-variation troubles have vanished, as we can set the regulator to a predetermined figure which we can choose, and we know that the voltage will remain at that figure indefinitely within ± 1 per cent." The author maintains that the fully-automatic induction regulator is preferable to on-load tap-changing if the apparatus is required to function frequently, and I believe that for on-load tap-changing transformers it is usual to arrange a time delay so that the operation cannot take place more frequently than at 2-minute intervals; whereas numerous induction regulators are operating satisfactorily in this country, year in, year out, without any time delay whatever. So far as I know there are no automatic on-load tap-changing transformers in service in this country. The question of power factor is mentioned in the paper, and it is interesting to know that an induction regulator will seldom cause the power factor to vary from unity by more than 0·5 per cent. The statement on page 1214 that thermal-storage cookers are unknown in this country is not correct, as a thermal-storage cooker has now been on the English market for a few months. In the table on page 1215 a figure of 0·5d. per kWh is given as the cost of losses. If, however, the authority is generating its own power, surely this cost should be covered by 0·2d., at which figure the advantage would be still further in favour of the regulated line. On page 1213 the author suggests putting the induction regulator at the sending end. This, I suggest, only applies to a substation on one's own system: if a bulk supply is obtained the induction regulator should be put at the receiving end of the bulk supply.

Mr. H. Diggle: My first comment on Mr. Charley's paper has reference to Table 1, which seems to be made up on the assumption (an incorrect one) that with a given naturally-cooled tank the temperature-rise of the oil is a direct function of the kW loss. Most transformer designers are aware that this is not the case, and when a comparison is being made of temperature-rise figures between 35 and 50 deg. C. on a directly proportional basis, the assumption is likely to lead to results which will not be borne out in practical tests. The other section of the paper in which I am interested is that dealing with on-load tap-changing. The statement that the parallel-winding scheme is becoming obsolete is borne out in this country to the extent that only one manufacturer now uses this scheme, although this firm uses it extensively. The General Electric Co. of America originated the parallel-winding scheme some two or three years before any British manufacturer adopted it. They themselves have now abandoned it in favour of the single tapped-winding method, with tapped auto-transformer and double selector switches.

One speaker has mentioned the use of the centre tap of the auto-transformer to obtain a running position, and has criticized it on the score of noise. It also has other disadvantages. Higher losses are involved, the choking coil or auto-transformer has to be bigger than it need be, and it adds not only to the load loss but also to the no-load loss in every alternate tapping position. The latter is a disadvantage when the no-load losses have to be capitalized at a high figure. The outline drawing of the 45 000-kVA transformer in Fig. 8 shows tap-changing gear of a type which appears to leave something to be desired from the user's point of view. In designing tap-changing gear it is necessary, in my opinion, to make those parts easy of access which are liable to require maintenance. According to Fig. 8, the tap-changing switches are contained in a tank 7½ ft. long by 3½ ft. deep. In order to inspect these switches it is necessary to remove all the oil from this relatively big tank, break the gasket joint of the cover, and then replace the cover after the maintenance work on the switches has been carried out. Designs of gear are available from at least two makers in this country in which these objections are overcome, and it is possible to inspect the switch contacts without any more trouble than that involved in lowering off the switch tank full of oil. The operating box for the motor driving gear is also inaccessible. In the design illustrated in Fig. 8 it is right on the top of the transformer, just adjacent to the high-voltage or the low-voltage terminals. From the point of view of maintenance the operating box ought to be arranged in a more accessible position, and it ought not to be necessary to shut down the transformer when work has to be done on this apparatus. The only other point on which I would comment is the step induction-regulator scheme mentioned on page 1201. This was originated in America 10 or 12 years ago, but has met with little success from the point of view of numbers of units built. It is difficult to see any special reason for adopting this scheme, particularly if a short-time rated induction regulator is used.

Mr. S. R. Mellonie: In connection with Table 1 of Mr. Charley's paper the figures given in the last line can be obtained approximately by assuming that the surface required is proportional to the square of the load current; thus the figures of radiating surface required are 1, 0·56, and 0·25, in place of the author's figures of 1, 0·52, and 0·29. The author follows common usage in expressing a temperature "gradient" in degrees Centigrade, but, as a gradient is a ratio, it would seem to be more correct to use the term "temperature-drop" if it is desired to express a difference of temperature in degrees Centigrade. The Buchholz relay is an interesting development and, if half the claims made for it can be justified, it will be widely adopted, but not to the exclusion of other protective devices. At present the royalties make the price excessive, and until this bears a more reasonable relation to the manufacturing cost of the article extensive application cannot be expected. Have any tests been made to determine the ability of the tap-changing gear described in the paper to stand up to short-circuit conditions? For example, trouble may be due to the freezing-together of contact surfaces, or the mechanical forces between adjacent conductors may reach dangerously high figures where they are brought close together. The temperature of 350° C. suggested in connection with the type of reactor shown in Fig. 17 is presumably determined by the type of insulation employed. If bare copper reached such a temperature, the surrounding oil would certainly be damaged, although, of course, this value is much below the temperature of the arc in an oil circuit-breaker. In any case, the oil would probably require attention more frequently than short-circuits on the system would cause the reactor to reach its limiting temperature. The question of the maintenance of the ever-increasing volume of oil in the transformers is not dealt with in the paper. In view of the several types of filters available for oil treatment, an expression of opinion from the author regarding the merits of the filter and the mechanical-separator types would be of interest. If the clearances inside the transformers are adequate the work of filtering the oil can be carried out whilst the transformer is on load, without jeopardizing continuity of supply. It would be interesting to know whether the author's experience enables him to endorse such a procedure.

Fig. 14 of Mr. Ayres's paper suggests two alternatives to the induction-regulator solution of the problem of voltage regulation. In the first place, if the transformer T were removed to the position indicated for the induction regulator, points A, B, and C would all be equidistant from the point of low-tension supply. Secondly, another small transformer could be installed at the place indicated for the induction regulator, and be coupled to the same high-tension oil switch as the transformer T by means of a short length of e.h.t. cable. This would enable the load at the point A to be supplied without undue voltage-drop. Local conditions may, of course, prevent either of these alternatives from being adopted, but where there is room to accommodate an induction regulator considerations of space would not prevent the substitution of a second 100-kVA transformer. The example given of transmitting 3 000 kVA at 11 000 volts over a distance of 12 miles undoubtedly makes out a very favourable case for the induction regulator, but if the transmission voltage were increased to 33 000 volts the annual cost of the line would be about half that shown, and the regulation would be slightly improved. To be complete the example should include a step-down transformer, which, of course, would considerably increase the percentage drop. This suggests that an automatic on-load tap-changing equipment in conjunction with such a transformer would prove an equally attractive proposition.

Mr. G. L. Porter: The tap-changing switchgear shown in Fig. 14 of Mr. Charley's paper includes contactors which have to break current at every tap change, as well as tap-selecting switches which do not operate under load. The need for accessibility is very different in the two cases, and the contactors should be even more readily accessible than an ordinary oil circuit-breaker. This requirement practically entails segregation of the contactors from the other switches. On the other hand, owing to their off-load operation, the need for maintenance work on the tap-selecting switches should be negligible, in which case their ideal position is inside the main tank adjacent to the tapped winding—particularly for high-voltage work, where the bringing of tap connections out of the tank is undesirable. If such an internal switch is used there is little objection to the additional taps required for the parallel-circuit method of obtaining the necessary overlap impedance. Any maker, however, who cannot trust his tapping switch inside the transformer tank will, of course, be biased in favour of the auto-transformer method, in view of the latter's saving in the number of taps brought out. The risk of burn-out with the parallel-circuit method should the tap-changing gear stop in an intermediate position, is referred to by the author. With properly designed gear this is merely a question of the risk of interruption to the auxiliary supply used for the operation of remote-controlled regulators, and the risk can be evaluated on the basis of the number of involuntary interruptions per annum and the proportion of the total time during which the gear is in a vulnerable position. Thus, if there are 20 tap changes per day and the vulnerable period is 5 seconds during each tap change, if there is one involuntary interruption per annum there is risk of trouble once in 864 years. Such a risk is not very serious, and, in any case, as transformers are usually run in parallel and the advantages of consecutive instead of simultaneous operation of the tap-changing gears is becoming appreciated, the risk of damage can be completely removed by the use of delayed split-conductor protection on the parallel circuits.

The form of control described by Mr. Ayres in which two potentiometers and a polarized relay are used is, of course, very old, but I have found it useful for the control not only of automatic regulators but also of the remote manual type. In the case of parallel regulators it is equally useful whether simultaneous or consecutive operation is desired, and is in both cases much more foolproof than push-button control. Where automatic control of parallel regulators is required the polarized relay for the "trailing" control is generally provided with extra contacts to prevent the leading regulator from moving more than one step until overtaken by the trailer. This ensures that failure of the trailer to follow will not result in the regulators getting so far out of step that there is risk of one becoming overloaded. I am puzzled by the neutral choke X shown in Fig. 14. There are, of course, cases where it is undesirable for the static balancer to be in parallel with the main transformer, but a break in the circuit is the usual and certainly the cheapest form of high impedance. I have studied the Electricity Commissioners' Regulations carefully and can find no justification either in letter or in spirit for the author's statement regarding a continuous conducting neutral. It has always been assumed, and rightly so, that a static balancer may be installed to provide a local fourth wire in conjunction with a 3-wire 3-phase supply, and that if the neutral of the winding of the main transformer is earthed the circuit has an earthed neutral. In a 4-wire system such as that illustrated, the static balancer is installed because it has a lower equivalent neutral impedance than the main neutral conductor itself, and it therefore ties the local neutral to earth potential better than the main neutral conductor would, even without the choke shown.

Mr. G. L. E. Metz (*communicated*): Mr. Charley refers to the use of dry air under pressure, or of an inert gas, for filling the tanks of transformers shipped out of oil. No mention is made of the shipment of transformers *in vacuo*, which, it is believed, has also given highly satisfactory results. It would be interesting to have the author's opinion upon the relative merits of the various methods available for the shipment of transformers out of oil. Reference is made on page 1192 to a 32 000-kVA Scott group where the low-voltage current is 340 000 amperes. I should like to know the type of conductor used to carry this heavy current and the type of insulator used to support it, since the skin and proximity effects would present a difficult problem at 50 cycles and the electromagnetic loading upon the conductors at 4-ft. spacings would be of the order of 2 600 lb. per foot run. Can the author state whether the use of inert gas in the "Inertaire" transformer (page 1196) eliminates the risk of oil fire? The author's statement with regard to Buchholz relays infers that they can be used in conjunction with any type of transformer. If they have not changed in design, this is incorrect, since their use is confined to transformers with expansion vessels. With regard to the question of reactors, it would be interesting to learn whether the remarks given in the paper are intended to apply to section or feeder reactors, since in the latter case the increase of 35 per cent loss of the oil-immersed reactor over the concrete reactor appears to be small.

Dr. J. L. Miller (*communicated*): My remarks will be confined to Mr. Charley's paper, particularly to Section (9), which deals with impulse and inter-turn insulation. I agree with the author that transformers should not be subjected to transient tests in the manufacturer's works. It is not always realized that the solid insulation in a transformer has a characteristic such that the damage done by transients is progressive and cumulative, so that whilst a 100 000-volt transformer might stand any number of 600 000-volt surges, at 800 000 volts only 50 surges might be required to break it down, and a single 1 000 000-volt surge might destroy part of the winding immediately. Therefore, although a transformer built by a reputable firm might stand several surges of the maximum value allowed by the line insulators, I do not suppose any manufacturer building a competitive and normal transformer would guarantee that his design would successfully stand 500 of these surges. For these reasons I think that impulse tests might be expected to shorten the impulse life of a transformer. There is the further difficulty, of course, of deciding on the maximum value of the surge to be used, and its wave-shape. In Section (9) no mention is made of electrostatic grading rings at the ends of the winding. I think it is evident, from purely physical considerations, that rings used in conjunction with suitably proportioned inter-turn and earth capacitances can do much to ease inter-turn stress. In this connection the following table may be interesting. It gives the inter-turn voltage of a series of transformers as a percentage of the voltage to be expected with an ordinary transformer equipped with no anti-surge devices The figures are taken from a paper* published recently. It will be seen from the table that Case 3 compares favourably with Case 5, without having the increased cost and complication of the latter. Referring to Table 2, I should like to know what safety factors have been taken into account in the preparation of the figures. Although one might imagine that a transformer designed in accordance with these figures would be lightning-proof, this will not be so. I have had no personal experience of the Buchholz relay, and I should therefore like to have the author's views on it. He mentions that the colour of the gas gives, to some extent at any rate, an indication of the fault. We have found that in the case of the minor breakdowns and small discharges which the relay is expected to detect before they become more serious and destructive, the gases given off are in general colourless. The many analyses which we have made indicate the presence of gases such as carbon dioxide, oxygen, unsaturated hydrocarbons, carbon monoxide, hydrogen, methane, and nitrogen. In more vigorous breakdowns, however, smoke with a brownish or yellowish appearance certainly came out of the test sample, but this was very soon dispersed, leaving the colourless gases as before. It would appear that the colour test does not give a reliable indication. I should like the author's comments on this point.

Case	Type of winding	Voltage (as a percentage) across a certain percentage of the end turns
1	Standard insulation	100
2	Standard insulation with end rings	66
3	Specially-designed insulation with end rings	27
4	Ideal winding with shields giving uniform distribution, i.e. a non-resonating transformer	10
5	Practical winding with shields	15

Mr. J. Solomon (*communicated*): With reference to the 32 000-kVA transformer built by Messrs. Savoisienne (page 1192), will the author supply further details of the secondary winding, which carries 340 000 amperes? In connection with the large reactors referred to on page 1203, it is interesting to note that the capitalized value of the losses in the three units would amount to about £26 280. This is based on energy at 0·50d. per kWh and a load factor of 50 per cent. The annual cost of the energy losses would similarly amount to £1 314. These figures, which would be proportional to the load factor assumed, indicate the cost of the energy losses in large reactors of this type.

[The replies of Mr. Charley and Mr. Ayres to this discussion will be published later.]

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* E. T. Norris: "Protection of Electrical Apparatus from High-Voltage Surges," International Conference on Large Electric High Tension Systems, Paris, 1931.

NORTH MIDLAND CENTRE, AT LEEDS, 24TH NOVEMBER, 1931.†

Mr. R. M. Longman: The growth in the size of transformer unit, particularly since 1925, has been almost incredible. The transformer may have overgrown its strength, and at all events it requires—and will possibly obtain—a fairly long rest period. What has been the chief cause of this rapid growth? In my opinion it has been the adoption of separate, forced cooling methods, in consequence of which the size of the actual transformer is now a relatively small proportion of that of the complete unit. This shedding of all the cooling equipment of the transformer has been of vital importance to transport, but it introduces trouble peculiar to itself. The transformer with self-cooling apparatus forming a part of, or directly attached to, the tank, is very compact and it is generally a simple matter to get a good lay-out for the unit. As the types and arrangement of coolers vary so much, however, a site suitable for one design may be almost useless for another, and negotiations for a new site have often to be undertaken, with rather dire results. I do not favour the arrangement resembling a huge eagle, in which the tank is in the middle and radiators are mounted on structures on either side. This form is unsightly and takes up far too much space. As a result of the last 25 or 30 years' experience, the transformer has come to be looked upon as the most reliable piece of electrical apparatus in existence, and I hope that it will still continue to occupy this pre-eminent position. As transformers are now encumbered with switchgear, pumps, motors, fans, pipes, automatic starters, relays, oil valves, etc., it is up to the transformer designers and manufacturers to raise all these accessories to the same standard of reliability. The railway and road-transport companies in this country have met the requirements of the Central Electricity Board and the transformer manufacturer in a very commendable manner. In 1919, when taking part in the discussion on a paper‡ by Messrs. A. G. Ellis and J. L. Thompson, entitled "Large Power Transformers," I suggested that the time might come when we should be able to transport these huge units by air. That time has not yet arrived, but when it does come we shall be free from the limitations imposed by railway gauges, bridges, etc. As regards single-phase and 3-phase units, the author's figures for weight and cost are quite conclusive. I have always favoured the 3-phase unit, and I think that from practically every point of view it is still the better proposition. The Berry single-phase, radial, shell-type transformer, however, possessed two very valuable properties, that of being the least noisy of its type and that of providing the best cooling arrangement for the iron. As a result of the latter property many of the old units show no sign of ageing of the iron or of increased iron losses. I doubt whether any other make of transformer has such a good record in this respect. The cooling of the iron in large transformers is a matter of considerable importance, and I do not think that this matter is fully appreciated at present. We shall probably know more of it in 5 years' time. A point to which the author does not refer is the flux density. In the struggle to obtain reduced costs, greater output within the permissible limits of transport, and more effective utilization of material, the flux-density value has been raised considerably and without due regard to its effects on a large system. The effects to which I refer are harmonics (principally the fifth and seventh) and noise. Harmonics are due to the magnetization hysteresis-loop of the iron, the area of which increases with the flux density. With low flux densities the principal harmonic is the third, which is wiped out, however, by a circulating current in the delta-connected winding. Unfortunately the higher harmonics cannot be dealt with so summarily. Whilst a few transformers of relatively small capacity having high flux densities can be and are tolerated on a large system, the presence of a large capacity of such transformers is bound to have a very harmful effect. I do not think the transformer designers and technical engineers concerned have given this aspect the attention which it deserves. Turning to the question of noise, one must bear in mind the capacity of the transformer unit, when judging the noise it emits. In this connection I feel sure that an increase in the amount of iron and a reduction in flux density would be an improvement. The 5-limb construction is a decided advance, and it emphasizes the trouble involved in assembling and cooling the iron. Another detail to which I attach especial importance is the supporting of all the leads. Under short-circuit conditions the stresses on the windings and connections of large transformers are enormous, and too much care cannot be given to the bracing of the windings and particularly of the connections to the windings at tapping points. It is probable that more failures have arisen from lack of attention to this item than from any other single source. With reference to inter-turn insulation, I hope that the new British Standard Specification will obtain as satisfactory a record of results as the older and rather crude one to which the author refers. I agree as to the desirability of using induction regulators on the low-voltage side of distribution systems. It must not be expected that the grid transformer will give all the regulation which may be required for the supply to domestic premises.

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† The paper by Mr. Charley was the only one read and discussed at this meeting.

‡ *Journal I.E.E.*, 1919, vol. 57, p. 547.

Mr. W. R. T. Skinner: In comparing the concrete type of reactor with the iron-core type, the author makes certain observations with respect to the former which seem to me to apply more especially to reactors consisting of a helix of bare wire cast into a number of radial blocks of concrete, the whole being mounted on a stand supported by insulators. There was, and probably still is, an alternative type of concrete reactor to which a number of the author's criticisms would not apply. I refer to the type in which the concrete structure had the general form of an alternator stator surrounding a coiled length of lead-covered cable. The cores of the cable were joined in series to make the number of turns in the solenoid an integral multiple of the number of turns of cable, the multiplier being equal to the number of cores in the cable. In particular, in regard to the suitability of concrete reactors for outdoor use, it was commonly claimed that such reactors could be buried in the ground as part of the cable system. It would be interesting if the author would indicate the basis of the expression on page 1203 for calculating the temperature-rise of the copper during short-circuit. Another matter of interest is the inherent reactance of transformers. The magnitude of supply systems at the present day, and still more the magnitude they are likely to achieve in the near future, make the provision of a certain minimum impedance desirable as an aid to switchgear. It is frequently advantageous to rely upon transformers to provide additional reactance for this purpose, and I should welcome a statement from the author as to the values of inherent reactance we can reasonably expect, and generally as to the effect of inherent reactance upon the economical design of transformers.

Mr. D. C. Field: In the past there have been certain limitations in the way of the building of larger transformers, but these have now been removed. At present, assuming that the problem of the cooling of large cores has been successfully solved, the limit in this country appears to be that of dimensions imposed by the loading gauge of the railways. Whilst it may be possible to build very large transformers within these restricted dimensions, I feel that in view of the trouble experienced with harmonics and noise due to high flux densities there will be an optimum size for transformers designed for rail transport. The author compares the cost of one 3-phase with that of three single-phase transformers, and states that his figures are approximately true for 3 000 kVA at 66 kV. For larger sizes than this, however, I think that the difference between the two costs is not nearly so great. I have in mind a 20 000-kVA bank of single-phase transformers of which the cost was only $33\frac{1}{3}$ per cent more than that of a 3-phase unit. Can the author suggest any ways of minimizing the noise emitted by transformers? One factor which can assist is the reduction of the flux density to a figure very much lower than that normally employed, even possibly to as low as 8 000 lines per cm^2. This, of course, would add considerably to the cost of the transformer. There are many points in favour of air-blast cooling as compared with water cooling. If axial-flow oil pumps are used the transformers can carry a considerable proportion of their rated load as natural-cooled units. Should the oil pump or fan fail at full load there is still sufficient cooling to enable the load to be carried until the defect is remedied or other means are adopted for carrying the load. In the case of water cooling, on the other hand, it is necessary to relieve the transformer of all load immediately the cooling equipment fails. I am not sure that everybody shares the enthusiasm of the author for the new British Standard Specification for inter-turn insulation. In the past there has been a rough-and-ready rule, and the amount of trouble experienced has been relatively small. The new specification calls for a smaller amount of reinforcement than that usually specified, and I do not think that the evidence in support of this reduction is conclusive. Until further information is available as to the behaviour of transformers under surge conditions, it is premature to adopt a specification which materially reduces the inter-turn insulation on transformers as hitherto manufactured. I am interested to note the author's reference to the question of phase shifters, which I think will become increasingly important. Voltage regulation alone is satisfactory with radial feeders, but when one is dealing with large interconnected systems it is impossible to dispatch the load as required and to make full economic use of the copper, unless means are provided for controlling the phase shift as well as the voltage.

Mr. G. E. Tansley: I am especially interested in the author's remarks concerning the various types of radiators. Cooling by means of air is analogous to oil or water heating by air, and therefore similar laws are applicable. A good deal of experimental work has been carried out in connection with gilled tubes for water heating by means of flue gases, and the experience gained should be useful in radiator design. As regards the author's contention that, with forced air-cooling, gilled tubes are not so effective as with natural air circulation, the reason for this may be traced to one or two causes. In the first place, unless the gill is in perfect contact with the tube the passage of heat from gill to tube will be seriously affected; and secondly, with high-velocity air unless the thickness of the gill near the junction of gill with tube is approximately one-quarter to one-third of the depth of the gill, the heating or cooling surface of the latter will not have its maximum efficiency. In an endeavour to design an efficient oil cooler embodying the above principles I evolved an apparatus consisting of steel tubes on which were shrunk gilled sleeves. The gills, however, were arranged at an angle with the axis of the tube, so that any air which might be heated by the gills would readily release itself. A complete section of such tubes was connected to an experimental transformer tank with natural air circulation, but although the results were fairly encouraging it was ascertained that the weight and cost of construction rather nullified the advantages. It would no doubt have been far more successful in connection with a forced air system, where the fullest advantage could have been taken of the thicker gills.

Mr. A. C. Bailey: Referring to Fig. 9, I should be glad to know whether the cost includes the cooler and other auxiliaries. Fig. 10 refers to a safe load indicator, which, I feel, will not be efficient unless one knows the hot-spot temperature of the winding. This, I should think, will vary with every design. If the designer himself does not know the hot-spot temperature, this indicator will fail to fulfil its purpose. It would be interesting if the author would describe the type of breather used on the "Inertaire" transformer. From the principle of the Buchholz protective device I should be inclined to think that this would be very sluggish in action, and that the patented electrical methods of protection would be much quicker. In my opinion, when the Buchholz relay causes a circuit breaker to open circuit the damage in the transformer will be grave. Referring to inter-turn insulation, I do not feel that a 50-cycle voltage test is comparable with a surge test. One can get two classes of insulation material which will give the same insulation strength at 50 cycles, but when they are subjected to steep-fronted waves the values given may not be equal at all. The result obtained depends on the relative permittivity of the insulation materials. For paper the permittivity is 3, but for varnished cambric it is $4\frac{1}{2}$. Referring to noises, I should like to know whether the chief cause of noise in the transformer is really a matter of flux density, or whether it is the fact that the laminations are of different thicknesses. If the latter is the case, it is up to the people who supply the iron to roll it to a thickness having a smaller tolerance. Reverting to inter-turn insulation, for the larger-capacity transformers additional insulation between turns is recommended. I am under the impression that for a transformer to be fairly immune from surges the ratio (electrostatic capacitance between turns)/(self-inductance) should be large. If one introduces more insulation between turns one reduces the capacitance and probably gets a weaker transformer. I should like to have the author's comments on this point. I know of only one case where a transformer winding has failed due to a surge, and this case was met with on a system subject to many surges. It appears to me that the American development of the non-resonating transformer is due to the fact that such a transformer is badly needed in America, where the surge conditions are more severe than in this country. Now that the sizes of transformers have increased so much, in many instances tanks are made in parts and joined together. I have seen some large transformers on which nearly all these joints leak slightly. Different transformer manufacturers use different jointing materials, and I therefore think that it would be worth while carrying out some research work to discover the ideal material for making these joints.

Mr. C. C. Higgens: No mention has been made of the life of large transformers. It seems to me that after a certain number of years should any trouble arise it will be difficult to get these large units back to the works. I should be glad to have some idea of their probable life.

Mr. I. H. Hedley: I agree with the author that shell-type transformers are doomed except for special purposes. At the same time it is interesting to note that the largest transformer made is of the shell type. I am glad to see that the author makes a proper analysis of the stress on shell-type coils under short-circuit. The inherent mechanical construction of the shell-type transformer allows of efficient clamping of the coils. Referring to the Continental method of making the transformer tank form part of the railway truck for transport purposes, I am glad that British electrical manufacturers have kept to their own job of making transformers, and have left the manufacture of railway rolling-stock to others. Modern transformer tanks are quite complicated enough already. The core ventilating system shown in Fig. 6 is excellent in theory and practice, but it must be expensive so far as punching and assembling are concerned. While ducts running along the laminations are not as efficient, they are so much cheaper that probably in the end they enable the same amount of cooling to be achieved at a lower cost.

I regard safe-load indicators as an excellent development, and they can be used to load a transformer to its maximum thermal rating. Calibration of these indicators presents difficulties, however, as this cannot, I think, be done without actual test figures on individual units. With regard to the Buchholz protective device, I should be glad of the author's opinion as to its efficiency in service, and the difficulties (if any) associated with its use. It seems to me that some difficulty will be experienced when the oil has to be cleaned and circulated through the transformer. I am glad to see that inter-turn insulation has now been put on a scientific basis, even if the new figures are not acceptable to everyone. In grading the insulation it is very important to see that the main body of the winding has a relatively high electric strength. The new British Standard Specification aims at improving this figure, and better transformers will result from it. With regard to on-load tap-changing gear, the majority of us would welcome something a little less complicated than the gear in use at present. In conclusion, I should like to ask whether any means of reducing the noise of transformers has been discovered of recent years, apart from that involving a reduction in the flux density.

Mr. E. A. Logan: Regarding the multi-core cables necessary for tap-changing gear, it would be interesting to know what the author would suggest as the probable upper limit to the number of cores necessary for transformer control. The present tendency appears to be for the number of cores necessary to increase. Can he assure us that this tendency will not continue? Certain advantages and disadvantages are attributed to shell-type as distinct from core-type transformers, and I should like to know exactly what constitutes the line of demarcation between the two types. The question of noise in transformers has already been largely commented on. Primarily, of course, the cause must be vibration, but is this vibration due to flexing of the core plates or is it due to actual change of volume of the iron itself, i.e. to the effect known as magneto-striction? The surge-proof non-resonating type of transformer appears to have many of the characteristics of the old type of transformer in which an earth shield was provided. It was universally disliked, and has now been almost entirely abandoned because of its inherent weakness.

Mr. W. M. Lydall: I should welcome the author's opinion on the cleansing of tanks. Of recent years much has been said in favour of sand-blasting tanks, but while many tanks of comparatively small capacity (say, up to 1 000 or 2 000 kVA) are sand-blasted, most of the larger ones are not. I am not in favour of sand-blasting, as I think that if it is carried out most of the fine dust still remains in the tank. If the tank is carefully cleaned by wire brushing, however, it will be found quite satisfactory, and the danger of dust will be eliminated. The question of noise is closely related to flux density. Incidentally, many engineers issue specifications in which they call for a mass of technical data, including a statement of flux density, copper density, etc.; it would be interesting to know whether these data are ever checked. If the designer were left free of commercial considerations, "noiseless" transformers could be made, but the flux density would have to be low and the cost of the transformer would be thereby increased. There is usually a difference of opinion between the commercial and the technical sides of a business, the former demanding a transformer for a limited price and the latter wanting to keep the iron losses down. It is practically impossible to meet both these requirements and at the same time produce a silent transformer.

[Mr. Charley's reply to this discussion will be published later.]

SHEFFIELD SUB-CENTRE, AT SHEFFIELD, 20TH JANUARY, 1932.

Mr. W. C. Kennett: Since Mr. Charley's paper was written, further large transformers have been designed and are under construction. A German manufacturer, for example, is making a 3-phase 100 000-kVA 50-cycle 220/110-V 63·5-kV transformer for the Herdecke hydraulic storage plant. In this country there are under construction two transformers for the Barking "B" power station, each unit being of 93 750 kVA British Standard rating and capable of a continuous output of 103 125 kVA with an ambient air temperature of 30° C. or a cooling-water temperature of 15° C. These may be justly described as the largest-rated power transformers yet considered, since the 100 000-kVA unit mentioned in Schedule I is auto-connected and corresponds to a true transformer of 54 000 kVA; likewise both the 100 000-kVA transformer in Schedule II and that which I first mentioned are designed to V.D.E. rules, under which the Barking transformers would correspond to a figure considerably in excess of 100 000 kVA. Actually, comparison of these ultra-large sizes is difficult, owing to variations in test rating, conditions of use, and number of windings. They are also the most efficient, excluding, of course, auto-transformers. Figures for the Barking transformers corresponding to those given in Schedule I (page 1204) are as follows:—Fixed loss 130 kW, load loss at full load 360 kW, full-load efficiency 99·47 per cent, star-connected on 33 000-volt side, delta-connected on 12 500-volt side, impedance voltage 9·82 per cent, weight of core and windings 89 tons, of oil 17 tons, complete 130 tons, transport weight 120 tons; excluding the coolers, they are 25 ft. long, 10 ft. 6 in. wide, and 20 ft. 6 in. high; name of manufacturer: Hackbridge Electric Construction Co. Two external water-coolers, each capable of dealing with the losses at 60 per cent load, are fitted to these transformers. They are of the 5-limb core type, and are specially designed to avoid harmonic troubles. Turning to Section 3, I agree with the author's conclusions regarding 3-phase as compared with single-phase transformers. It might be added that the 3-phase unit is superior not only in cost but also in efficiency and in the space required for installation. Opinion in America appears to be moving in favour of 3-phase transformers, following European practice just as it did a few years ago in adopting the core type. Thus a recently-ordered Canadian transformer of 46 500 kVA for the Beauharnois scheme and six 36 000-kVA units for the Shawinigan Water and Power Co. were all of the 3-phase type. A forthcoming pair of 50 000-kVA transformers for the Ontario Hydro-Electric Commission will probably also be 3-phase. While it is desirable to know the temperature of the windings in these abnormal sizes, the indirect method often used and of which an example is given in the paper is of doubtful value and is based upon assumption. Direct measurement, the only real indication of temperature, is impossible owing to difficulties in insulating the active principle in the measuring instrument. The non-resonating construction mentioned in Section 10 is ingenious but its use is unnecessary. The transformer is now probably the strongest link in the chain between prime mover and consumer, and it is desirable not to spoil its inherent simplicity of construction by complication that can be avoided. The same comment applies to devices for on-load voltage regulation. Most manufacturers can now equip their transformers with on-load tap-changing gear, but even the best of this gear is less dependable—due to its complications and moving parts—than the transformer which it accompanies. The economic advantages generally outweigh the technical advantages of mounting the on-load tap-changing gear direct on the transformer. Capital cost is the primary consideration that militates against the more extensive use of a regulating device separate from the main transformer. This latter method provides greater flexibility of operation and permits of the transformer being operated during the periodical inspection or overhaul of the regulating switchgear. The ordinary regulator for varying the ratio of the transformers linking power stations is only of use for the control of the wattless load. The distribution of power load is ruled by the governor settings on the turbines, or by the use of a combined tap-changer and phase-shift regulator. This type of equipment will undoubtedly be in considerable demand in the near future. The paper indicates that British engineers are holding their position abreast of the most advanced engineering practice in the world.

Dr. T. F. Wall: The value of Mr. Ayres's paper would have been enhanced if it had been somewhat less compressed, since there is not a great amount of detailed technical literature available in an easily accessible form in connection with the newer applications of the induction regulator. In this connection, is the statement at the bottom of col. 1, page 1209, a theoretical conclusion or is it an empirical result? It would have been interesting to have had more information on the subject of the efficiency of operation of an induction regulator with regard to the transmission-line losses. For example, it is known that, in the case of a closed loop supplied by one generator, if the ratio of the resistance to the reactance of each section of the loop is the same the current will distribute itself so that the line losses are a minimum.* If a booster voltage be injected into the loop a circulating current will be produced, the magnitude of which will be given by the injected voltage divided by the impedance of the loop. The transmission-line losses due to this circulating current may be considerably greater than the normal line losses due to the load. This harmful circulating current can be eliminated by the use of the twin regulator. If, however, the sections of the loop do not comply with the conditions for minimum transmission-line losses, i.e. if the ratio of the resistance to the reactance of each section is not constant (as will frequently be the case), is the induction regulator ever used to inject a voltage into the loop that will cause the current distribution to become more like that corresponding to minimum transmission-line losses? I should like to inquire whether the oil-pressure method for controlling the regulator is not preferable to the induction-motor method of automatic control described in the paper. The oil-pressure control system has no contacts, can act with extreme rapidity, and would seem to be a very satisfactory appliance.

[The replies of Mr. Charley and Mr. Ayres to this discussion will be published later.]

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* *A.S.E.A. Journal*, 1931, vol. 8, p. 104.

DISCUSSION ON

"THE DESIGN OF A DISTRIBUTION SYSTEM IN A RURAL AREA."*

NORTH-EASTERN CENTRE, AT NEWCASTLE, 23RD NOVEMBER, 1931.

Mr. H. D. Phelps: In laying out their Model Scheme the authors seem to have put the cart before the horse; first they have laid out their high-voltage system, then their low-voltage distribution system, and finally they have looked around to see what revenue must be obtained. Commercially, one works in exactly the reverse order. Fig. 5 shows that the Central Electricity Board's 132 000-volt lines are relied upon to provide all the points of supply, and these are in fact tapped every 20 miles. I had always understood, however, that these 132 000-volt lines could not be tapped so frequently. I do not believe that, for many years to come, we shall see 132 000-volt substations scattered throughout rural areas. No rural scheme could earn sufficient revenue to pay for them. As the authors assume that 132 000-volt substations will be provided where required, why do they bother to arrange for a secondary high-voltage system of 33 000 volts? Surely an 11 000-volt network would have catered for the rural area, seeing that the greatest length of feeder would be approximately 10 miles. If, however, the anticipated load is estimated to exceed the economical range of 11 000 volts, due to a group of collieries or a town being situated in the area, why not adopt 20 000 volts instead? If this were done there would only be two voltages, i.e. 132 000 and 11 000 volts, or for heavier loads 132 000 and 20 000 volts, instead of the three—132 000, 33 000, and 11 000 volts—suggested by the authors. In support of this proposal I would state that the pin-type insulators advocated for 11 000-volt lines are absolutely reliable on 20 000 volts. They have been used on this voltage for many years in the North-East Coast area, while abroad they are used for considerably higher voltages. Small single-phase 20 000-volt transformers are perfectly reliable, and in 20/25-kVA sizes they only cost 20 per cent more than the 11 000-volt type. Combined fuse isolators for 20 000 volts, operated and replaceable from the ground, will shortly be placed on the market by English manufacturers, though abroad they are manufactured and used at 33 000 volts. The additional cost of the 20 000-volt compared with the 11 000-volt apparatus will be compensated for many times over by the savings effected through eliminating the 33 000-volt system. It is fairly safe to assume that to obtain the largest spans, 0·05-sq. in. copper or the equivalent will be used for all voltages, except perhaps in the case of short spur lines, when 0·025 sq. in. might possibly be considered. Even for this type of line this size will be very small, and might not be heavy enough for the ultimate load desired under the Model Scheme. As regards the cross-arm designs shown in Figs. 18, 19, 20, and 21, the pole-top insulator looks like an afterthought and would be a tremendous temptation to anyone with a catapult or rifle. The design shown in Fig. 22 looks as if it does not need bird guards, and it would seem to be very advantageous for converting an existing single-phase line to 3-phase, the bottom arm and insulator being easily added. Turning to the schedule of costs given on page 225, I should like to ask the authors whether they are willing to erect short lengths of main 3-phase 11 000-volt line for £375 per mile, and of span line for £235 per mile, in an average rural area. Are the prices quoted applicable only to 100-mile lengths? Regarding l.t. lines, the shackle-type insulator is not so noticeable as the swan-neck type, and the least noticeable of all is the Aylesbury type of "through the pole" insulator; but it may have disadvantages from other points of view. Turning to Fig. 26, is not the l.t. line attached too high up the pole? It must be remembered that one might want to work on the pole with the h.t. line alive. Also the l.t. fuses cannot be reached without making the h.t. line dead, which may mean shutting down a large area. The regulation earth-testing panel is apparently not shown at all. Should not all the l.t. apparatus be housed in a weatherproof wood or steel cupboard, conveniently situated at the foot of the pole? I should be glad if the authors would give details of the various items which make up the sum of £52 stated to be the cost of providing, transporting, and erecting a 15-kVA 11 000-volt oil-filled transformer and equipment at 10 miles from headquarters. Perhaps the authors would at the same time give the cost of a 25-kVA kiosk substation supplied from the 11 000-volt underground cable. I am in favour of the authors' methods of reducing the costs of line construction. Although it may be too expensive to include spur lines in the original lay-out, the tapping points should be provided on the main lines just as distribution points are provided on l.t. networks. The authors are in favour of providing 5-kVA transformers for some installations; it seems to me that, except in isolated cases such as bungalows, this size would be too small to allow of full advantage being taken of the uses of electrical energy. On the North-East Coast I am afraid this size would be no good at all. The villages catered for in the "Statement of Capital Expenditure" (page 226) must be very small and compact, as 500 yards of network do not go very far in a straggling English village. In addition, the copper cross-section of the l.t. lines does not seem commensurate with the load which will be necessary in order to provide the necessary revenue. Turning now to the revenue aspect, I am in favour of all the methods mentioned on page 192 for promoting the use of electrical energy. Country dwellers are certainly more eager for electricity than town people, but to them it is something of a novelty—as it was to industrial areas 30 years ago. The industrialist now takes the electric motor for granted, although at one time he had to be educated to its use by hire, maintenance, easy-purchase schemes, etc. Not so the countryman; he is doubtful of the ability of the electric motor to do the work. In cases where doubt is evident, it is well to install a motor on site with temporary connections, free of cost, to convince the person concerned of its ability to do the work, and then to point out its advantages. This also applies to cookers and other apparatus, in connection with which I advise the following procedure. Install the equipment with temporary wiring and a meter in circuit for a month's trial, free of rentals, etc., make two or three visits during the period, and point out the consumption and the means of reducing it. If this course is followed there will be very few returned cookers or dissatisfied consumers. I should like to know whether the farm consumption and revenue given in Table 7 includes the house lighting and heating, as well as farm lighting and power. The average price of 2·29d. per unit seems very reasonable if this is so, considering that so many farms only have lighting connected. The results given in Tables 9 and 10 are all very good, but they seem to be much above the average. As regards Table 12, would rural electrification be possible at the price per unit paid by households Nos. 5 and 6? The paper gives the impression that, having arranged an ideal h.t. distribution system, the authors have also arranged the consumption to produce an ideal revenue. The remarks on potential uses of electricity rather point this way; for example, a 4-h.p. fan would be far too powerful for the average forge. The standard size of fan attached to a North-East Coast country forge only requires a $\frac{1}{2}$-h.p. motor to drive it, the revenue from this being a few shillings per annum. During the past few years the true rural population of the countryside has been depleted, owing to a change in methods of farming. Land is going more and more out of cultivation, and farming is becoming of a shepherd-and-dog nature. This, combined with falling wages, makes rural electrification schemes difficult to operate. It is doubtful whether the inhabitants of rural areas can afford much beyond electric lighting, and then only by the aid of hired wiring, or long-term easy-purchase of the installation. The depression in agriculture is far more acute than most town dwellers realize, as is revealed by the following examples. Last May a farmer in our area dispensed with the services of 13 men, and he is putting still more acres down to grass, which will probably mean discharging a further 10 men next May. Had this farm been retained as an arable one (the land being most suitable for ploughing), threshing alone would have accounted for some 6 000 units per annum. The attendance at a village school in the centre of another good arable district has dwindled from 100 scholars to 40, due to the land going out of cultivation and labourers having to leave the district. In conclusion, I would point out that the paper would have been more valuable if the authors had dealt with the electrification of actual rural areas comprising plains and river valleys interspersed with ranges of downs and hills, such as are found in England generally, and in which there are no towns, collieries, quarries, brickfields, etc., to provide the much-needed revenue.

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* Paper by Messrs. E. W. DICKINSON and H. W. GRIMMITT (see page 189).

Mr. G. S. Lisle: The North-East Coast district contains some 4 060 square miles of country districts where the average population is 160 per square mile, and approximately 200 miles of country distribution mains are already in use. The rapid progress that has already been made in this area is largely due to the adoption several years ago of the conditions (*a*) to (*g*) set out on page 192, which the authors regard as the basis of their Model Scheme. The authors state no principle which is not already known and put into practice in this area. The paper gives the impression of being based to a considerable extent on the Bedford Demonstration Scheme. Assuming that this scheme or the authors' Model Scheme represents average conditions in rural England so far as density of population and probable number of consumers are concerned, it does not follow that the wealth of the community in either of the model areas is fairly representative of the wealth of other rural areas. The authors state on page 193 that "semi-urban areas around cities and boroughs have been tackled first." This is only natural, but I do not agree with the statement which follows—that the problem of giving supplies on an economic basis in areas with decreasing density and irregular dispersion has still to be solved. The solution, so far as a paper solution of such a problem is possible, is already known; it remains to apply that solution—together with the several years' experience gained from those areas where rural electrification has already been carried out on an appreciable scale—to those areas where developments have not yet been taken in hand. I am in agreement with the authors when they advocate the necessity of looking at a scheme as a whole and not dealing with an area by sporadic developments, which, I am convinced, lead to much waste of effort and capital expenditure. The authors rely to a great extent upon the revenue to be obtained from power loads, and I think they will agree that without this revenue rural electrification on an economic basis would be impossible. Reference to Tables 7 and 16A shows just how valuable this revenue is. According to the former table, the revenue from factories, per consumer, is over 13 times the sum of the remainder, and Table 16A shows that in the sixth year of operation the revenue from 50 large consumers out of a total of 9 530 is 23 per cent of the total. Nowhere in the paper do the authors refer to the possibility or methods of giving street-lighting supplies, or to the revenue value of this load. I find it difficult to visualize a village of 92 consumers using 1 000 units each per annum in the sixth year of operation. The figure given in Table 23 for village loads is equivalent to approximately 0·5 kVA of substation demand per consumer. This seems a very high figure to attain in 6 years, and I suggest that 0·25 kVA per consumer would be ample. This need not mean that a system should be so designed that it is incapable of being reinforced as required to meet growing demands, but in the earlier stages of a scheme electricity supplies have to be made available before the demand for them exists, and the obtainable revenue is therefore relatively small. Consequently it is essential that the cost of the high-voltage distribution system, which accounts for a large percentage of the total capital expenditure required to offer the initially unremunerative supplies, should be kept to a minimum consistent with a reasonable standard of service and system flexibility. With regard to transformers, I think it is a mistake to install units of various sizes from 5 kVA upwards. A very slight extra load makes it necessary to replace these small transformers, which is an expensive matter. In this area a 25-kVA unit has been standardized for pole-mounting substations. This size has been arrived at not from any theoretical considerations but as a result of experience. The difference in first cost between a 5- and a 25-kVA unit is very little compared with the expense involved in replacing transformers. Standardizing 25-kVA units enables 50-kVA supplies to be given by means of two such units in parallel; in this manner it is possible to carry standardization of design to the limit, as all pole-mounting transformers of a given ratio can be made interchangeable, and the transformer hangers, pole ironwork, and pole design can be standardized. This arrangement enables transformers to be purchased in bulk, keeps down the amount of capital required for spares, and is very flexible. The authors do not refer to the feasibility of giving single-phase supplies. Reference is made to 3-phase lines for giving 5-kVA supplies; surely this is an extravagance which can only be permitted occasionally, in exceptional circumstances. A considerable number of such small supplies have successfully been given single-phase either through single-phase transformers mounted on the straight-line poles of a 3-phase line or by single-phase spur lines. Single-phase supplies are quite permissible where no large 3-phase motors are to be connected, and they do not appreciably affect the h.t. distribution system. If 3-phase loads are likely to develop, provision can be made on the spur line for adding the third conductor when required, and thus the immediate capital expenditure is reduced without sacrificing flexibility. In my opinion no rural supply scheme can be made an economic proposition without giving single-phase supplies to the smaller consumers and villages. I am in agreement with the authors' decision to use 11 000 volts for h.t. distribution in new areas, this being probably the most economical voltage when considered in conjunction with the secondary "grid" voltages and the most economical spacing of substations. The authors' statement that transformers up to and including 11 000 volts need not be fitted with conservators is quite contrary to experience in this part of the country, where conservators are essential to secure the maximum of reliability. The illustrations of pole-mounting substations show that the authors follow the old practice of providing a fuse-link on the h.t. side of each transformer. Presumably these are meant to protect the line against a failure of the transformer, since fuses are also provided on the secondary side which will take care of overloads and short-circuits on the low-voltage network. Are h.t. fuses really necessary? The modern British transformer is a reliable piece of apparatus, and experience has shown that if careful attention is paid to certain details of design it will give no trouble. On the other hand, however well designed a line may be it is liable to damage from such causes as broken insulators due to stone-throwing, tree branches thrown across the line, and kite strings; more interruptions of supply are caused through trouble on the lines themselves than by the transformers. Why, then, spend money on providing fuses to guard against what is not likely to happen? The best of fuses is an unsatisfactory piece of apparatus for controlling 3-phase supplies. Fuses are more satisfactory on single-phase supplies. The authors do not indicate the extent of the arrangements they would make to facilitate maintenance of the lines and fault location, or for adding additional spur lines and tapping points without interrupting the supply to other consumers. These matters require careful consideration, particularly where farms which employ heating for chicken incubators are concerned. Suitable arrangements can be made to meet these conditions. For maintenance purposes it is necessary to provide line section isolators, which can consist of one of the many forms of pole-mounting switches available every few miles. For want of something better at the same cost, isolators and fuses (preferably of the pull-down type) should be provided at the tee-off point for spur lines. This is a different thing from providing isolators and fuses at each tapping point, as each spur line may supply several isolated supplies which could be directly connected to the line. The designs of pole-mounting substations shown in the paper are capable of improvement. For instance, in Fig. 26 the l.t. fuses are located in a very inaccessible position. The existing Regulations of the Electricity Commissioners and, I believe, their proposed revised regulations, place certain obligations on the supply undertaking regarding the measurement of leakage current to earth. The authors do not indicate how they would meet these obligations.

Mr. G. G. Mallinson: Experience confirms that 11 000 volts is the best voltage to adopt for the networks of rural areas, and that steel-cored aluminium of 0·05 sq. in. equivalent copper cross-section should be used for the main lines. I disagree with the suggestion that 350 ft. is the best span for this conductor. The authors mention that 450-ft. spans are being used at Norwich, but state that an undulating countryside may prevent the adoption of this span length. This has not been our experience. A long span can be better than a short one in undulating and broken country. The longer span means fewer wayleaves for the mileage scheduled, and fewer poles in the middle of fields. Table 25 shows that the difference in cost between 350-ft. and 450-ft. spans is £2 per mile, but this difference in cost will be more than balanced by the capitalized value of the extra wayleave rentals. I do not see that the authors have made out a case for 350-ft. spans, in view of the prices shown in Table 25 and their remark on page 212 that "It cannot be too greatly insisted upon that the longer the span the better from all points of view." In Table 25 400-ft. spans are scheduled as giving the lowest cost, whereas our investigations show a minimum cost for 450-ft. spans. On page 212 steel conductors with 525-ft. spans are mentioned; in this connection I would point out that a large mileage of overhead lines has been erected with 535-ft. spans. The difficulties mentioned at the top of the page are not serious, and when allowance is made for them the cost for long spans is still the lowest. The pole required for the 535-ft. span would be 28 ft. long by 12¾ in. diameter at 5 ft. from the butt; this is not an outsize, but is obtainable in large quantities at a reasonable price. The authors' remarks on this subject refer to main lines, however, and I therefore agree with their conclusion that steel conductors should not be used but that 0·05-sq. in. copper equivalent should be adopted. As regards the pole-top designs, the pattern shown in Fig. 18 has been successfully used by us on about 130 miles of line. The fibre guards associated with this type have, however, the disadvantage that they form excellent nests for small birds. I prefer the type shown in Fig. 20, which is slightly cheaper than that in Fig. 18. This design has been used on the Norwich scheme and about 350 miles of other lines. The foundation proposed is excellent, but I am unable to agree that kicking blocks are essential in ordinary ground. Even with the longer spans which we prefer, operating experience has shown that if the pole is planted deep enough no trouble will result without blocks. The depth should be 7 ft., except where stays are used, when 6 ft. would be suitable. Planting poles at this extra depth is cheaper than fitting foundation blocks. At terminal and large-angle positions, foot blocks to take the vertical loads will be necessary if foundation blocks are not fitted. I am glad to see that it is not proposed to allow local farmers to put up lines. If this were permitted there would be endless operating troubles due to bad workmanship, and the probable effect on other consumers of numerous faults and shutdowns does not bear consideration. I disagree with the statement that 0·035-sq. in. copper spur lines would be cheaper than, or as cheap as, steel lines. The authors certainly qualify this by "where the total distance is short, the course uneven, and wayleave difficulties are absent," but such conditions are not representative of the 192 miles of spur lines scheduled. These spur lines will be from, say, ½ mile to 2 miles in length, and the wayleaves will always be a difficulty. The authors adopt 200-ft. spans, contrary to the opinion as to length of span which they express on page 212. On page 216 it is stated that on spur lines there are practically no wayleave difficulties as the lines are nearly always on the consumer's property; this is not always the case in this district. Even where wayleaves present no difficulty, the farmer will not welcome a large increase in the number of poles in the middle of his fields, and it must be remembered that with the author's 200-ft. span about 5 000 poles will be required as against 1 900 with steel lines. The wayleave difficulties would be enormous, and I regard 200-ft. spans as quite out of the question. This matter also affects the annual cost of wayleaves rentals to an important degree. Referring to the various switchgear arrangements, I note that the link-fuses in Fig. 25 should be operated by rods from the ground, presumably by means of a separate operating pole. It would be interesting to have some further details of these removable fuses. I note that l.t. fuses are not shown. I think these are advisable and I note that the authors recommend them on page 220. In Fig. 26 an "H" pole is used for transformers from 15 to 50 kVA, whereas I should be satisfied with a single pole for anything up to 25 kVA 3-phase, and 35 kVA single-phase. The type of switchgear shown is not easily arranged on a single pole, and I therefore consider that the design shown in Fig. 25 should be used up to the 25- and 35-kVA sizes. The position of the l.t. fuse box in Fig. 26 would be much improved if it were placed much lower down, on the level of the transformer terminals. No details are given of any switchgear apart from that for controlling the transformers. I gather, therefore, that all spur lines are taken off solid.

Mr. E. H. E. Woodward: It is difficult to generalize on the subject of rural supplies, due to the great variation in the type of area which can be described as "rural." For instance, the North-East Coast power companies supply rural areas with populations ranging from 26 to over 1 500 per square mile. Incidentally, they also supply an urban area with a population of only 51 per square mile. The authors' figures show that to a large extent areas at present supplied and spoken of as "rural" are really industrial, as 80 per cent of their present consumption is in respect of power as against only 72 per cent (which includes traction) for the country as a whole. The authors mention that the general design or lay-out of a supply system must have due regard to the Act or Order under which the work is to be carried out, and to the Regulations issued by the Electricity Commissioners. A little later they state that as regards these requirements, the Regulations issued by the Electricity Commissioners offer on the whole no impediment, but they make no reference to the possible effect of the Act or Order. There is one direction in which an Order can offer considerable impediment to development, and that is by reason of the option of purchase by a local authority. This may be particularly so in the case of a rural area, where much expenditure may have to be incurred with a view to an adequate return at a comparatively distant date. The authors are to be congratulated on the fact that they steer clear of calculations based on units per head of population from which so many fallacious deductions have been made. It is, however, a great pity that they include in the paper a curve relating units per consumer with average price per unit. The seeming relationship between these two factors is far more due to each being affected by similar causes than to the limited connection which undoubtedly exists between them. The curve shown in Fig. 9 includes units derived from all types of loads in rural areas, and is not arrived at after excluding power loads. What it really means is that where there is a large power load the average price per unit in the area is naturally reduced and at the same time the number of units sold per consumer is increased. This is particularly the case where there is a considerable high-load-factor load, often taken in bulk and at transmission voltages, as is the case in colliery districts where electricity is used for pumping and ventilating purposes. If we reject this relationship between average price and units per consumer, it is difficult to see how the revenues per consumer given in Table 15 can be justified, as they seem to be much in excess of actual experience. If they are not realized, the financial result of the scheme will be seriously affected.

Mr. B. H. Leeson: I should like to consider the probable total annual consumption to which the rural load could be developed. Taking the total rural area of England as 45 038 square miles, under the Model Scheme (density 150) having an area of 384 square miles with a sale of 16 678 000 units per annum the total yearly consumption obtainable from rural England would be about 2 000 million units. A similar figure is obtained from the product of the rural population in England (7 059 547) and the 290 units consumed yearly per head of the population in the model area (290 units = 16 678 000 units ÷ population of 57 600). Expressed in another way, the equivalent of about 120 such model schemes will have to be developed. The yearly consumption by rural England of 2 000 million units obtained from the authors' figures compares favourably with that contained in a general forecast* I made recently of the total consumption of electricity in Great Britain during the next 20 years. I predicted that the annual consumption in rural areas would reach 1 000 million units in 1940, 2 000 million units in 1950, and an ultimate figure of 2 500 million units. This forecast was made on a different basis, namely that in Great Britain there were about 263 000 farms exceeding 50 acres, and that the electrification of the 600 000 h.p. they are estimated to employ would be accompanied by further electrification of the neighbouring villages and the consequent displacement of some 66 000 oil and petrol engines. I should like, however, to concur with the plea that rural electrification should not be judged merely in terms of the amount of load or direct revenue it is likely to provide, but that it should be considered also from the point of view of the beneficial assistance it can render the electrical industry as a whole by reason of its advertising value, the benefits it can bring to the vital industry of agriculture, the encouragement it can give to village industries, and the general improvement in conditions which it can bring about in the country.

[The authors' reply to this discussion will be published in a later number of the *Journal*.]

NORTH-WESTERN CENTRE, AT MANCHESTER, 24TH NOVEMBER, 1931.

Mr. W. Fennell: In choosing an area of 100 square miles for technical purposes and one of 400 square miles for administration purposes, the authors have hit upon very convenient dimensions. The only difficulty is that in actual practice supply engineers have to deal with areas of all sizes, to meet the requirements of which the whole organization has to be varied enormously. A radius of 20 miles is practicable to-day for administration purposes. It enables one to concentrate the staffs at a central point, instead of having them spread all over the area. The authors apparently propose a 2-part tariff in which the fixed annual charge is not in proportion to anything tangible. How we could explain such a tariff to the consumer I do not know. In some tariffs the fixed charge is proportional to the rateable value, in others to the floor area, and in others to the lamp connections. In the Mid-Cheshire area we have as a basis the number of lamp connections, which are classified into three grades charged at different rates, viz. (*a*) peak-load lamps, (*b*) evening-load lamps, and (*c*) occasional lamps. The authors' unit charge goes down with increased consumption in a way not easily explainable to the public. I deprecate the introduction of another fixed-charge basis now that we have at last educated the public up to the idea of a 2-part tariff. The authors' figures show the running charge to be approximately 4½d. per unit for the first 200 units, 1d. per unit for the next 300, and 0·74d. per unit for the rest. I should like to mention that the principle of grading the unit charge is not entirely new, as in the supply area with which I am associated we have been employing it for the past seven years or more. For the first 100 units per quarter we charge 2d. per unit, for the next 100 units 1d. per unit, and for the remainder ⅝d. per unit. I cannot, however, see how a fixed charge which is reduced in steps with increase in the consumption can be made a success, as it would not be easy to explain it to the average consumer. Fig. 11 shows the central point of the 400 square miles with four apparently single lines radiating from it to the four sub-centres, each controlling 100 square miles. At the centre of each area of 100 square miles is a town area, and unless each of these centres is supplied in duplicate the whole of the scheme is jeopardized. The 33 000-volt are more likely to fail than the 11 000-volt lines, and if work has to be done on one of the latter, even if there is no failure, the supply to 100 square miles is cut off unless a duplicate line is provided. The extensive use that the authors propose of 4-wire distribution, for supplying "villages" as they term them, is not capable of very general application. A great portion of this country to-day does not consist of villages isolated by tracts of almost uninhabited country. Great Britain is fast becoming a ribbon-built suburb. Probably 30 or 40 years hence there will be houses along the entire length of the roads, except where they lead over open moors, etc. The 4-wire system, while suitable for dealing with villages of 200 yards radius, is totally unadapted for dealing with areas in Cheshire, portions of Lancashire, and North Wales, where the larger houses are not in the villages but a quarter of a mile or more outside. It is my experience that one must be prepared at short notice to supply up to 5 or 6 kW to new houses anywhere in the area. Thus to a great extent the Model Scheme is out of date when it is put forward, although I do not deny that there are parts of England (e.g. Norfolk, Suffolk, and Bedfordshire) where the villages are of the type which the authors describe. The authors express the operating expenses as percentages of the capital outlay, but as running expenses have to do with the number of consumers, the mileage of line, and the type of system adopted, it is improbable that the estimates are correct. To a less extent their estimates of income are open to criticism. I have compared the revenue figures shown in Fig. 3 with the actual income obtained from rural districts. While the percentages of consumers producing a revenue of £2 to £10 per annum each do not follow the authors' curve, the average result is much the same, i.e. approximately £6 per annum per consumer. While I congratulate the authors upon their high-tension lay-out, I consider a scheme based upon wholesale low-tension distributing mains to be quite out of the question.

Mr. W. A. Coates: Rural electrification has developed beyond a mere national ambition, and has become almost a national necessity. If rural electrification work is not satisfactorily carried out our profession will cease to be successful, because the industry will be loaded up with unnecessary, high capital charges. The authors themselves seem to me to doubt whether under present conditions we are likely to get the successful electrification that is desired. In some districts it has been accomplished, but we have only to look at the left-hand side of Figs. 9 and 10 to realize that there are many undertakings which have not gone very far along the road to success. Because I share in these doubts, I make no apology for referring to what has been done in another country, New Zealand. That country has an overall population density of only 14 per square mile, i.e. something less than one-tenth of the figure taken in the Model Scheme; yet 93 per cent of the population live within the range of an electricity supply. The last annual reports show that the consumption amounts to 490 units per head of population, the revenue to the supply authorities being 1·48d. per unit. The whole of this is practically a post-War development. Before the War the big cities and the larger towns alone had electricity supply; it should be noted that New Zealand's biggest city has only 200 000 inhabitants. The secret lies in the New Zealand Power Boards Act, one of the cleverest pieces of legislative compulsion that has ever been devised. It works in this way. The whole country is divided into about 45 districts, each being administered by an elected body known as a "power board," constituted on very similar lines to one of our county councils. The power board is responsible for reticulating its own area, purchasing power in bulk from the Government's stations. When the board is first set up, a canvass is made section by section throughout the area. If in any district 30 to 40 per cent of the possible consumers say that they want to have a supply, it is incumbent on the power board to run mains throughout that district. No guarantees are called for from potential consumers. If there is a loss on the running, the board has the power to levy rates, but any ratepayer can claim to be supplied with electricity free up to the value of his rate. Obviously, therefore, the non-user of electricity really has to bear the burden of excess cost. While it would perhaps be true to say that this arrangement is grossly unfair, it has worked successfully in practice. In point of fact, each year only three or four of the boards have had to levy a rate, and according to last year's report the maximum rate levied by any board was £6 000. One or two of the rates only amounted to a few hundred pounds. Only one board has had to levy rates for more than three years after it started. While I do not suggest that this method could be applied over here, so great a part of England is totally untouched electrically that it seems conceivable that those who are responsible for drafting the electricity laws could benefit by a study of the New Zealand Power Boards Act. In New Zealand four or five years ago, 11 000-volt 3-phase spur lines were being erected at a capital charge of £120 per mile, while in the South Island, at any rate, main lines were costing £180 to £200 per mile. These figures compare with the £355 and £375 respectively quoted in the paper. The mechanical and electrical factors of safety are substantially the same in both countries, because in fact the English regulations have been taken as the basis of those in force in New Zealand. A principal reason for the difference lies in the question of wayleaves. The landowners are so keen on electrical supply that wayleaves are granted automatically on the receipt of a notice indicating the positions where it is proposed to plant poles on the land, and stating that a rental of 1s. per year per pole will be paid. A figure of about 15s. per pole has been mentioned as the cost of obtaining wayleaves in a certain part of England. Again, if the New Zealand Post Office lines are found to be passing from one side of the road to the other, the power board can force the authorities concerned to keep them on one particular side. A feature which has some bearing on the cost of New Zealand's overhead lines is that in some districts local timber is used. I imagine, however, that the majority of authorities in New Zealand are using either Australian timber or concrete, and in some districts they succeed in making the latter pay. I should like further information as to the authors' suggested use of kicking blocks at the pole foundations. In other countries pole-foundation digging machines are being used, and it is always claimed that they represent a great economy in erection. Clearly, if kicking blocks are used it is impossible to employ a digging machine. I should like to know whether in other countries the poles are sunk deeper than the authors propose to do over here. I disagree with their views on the relative merits of fuses and circuit breakers. They seem to regard a circuit breaker as a dangerous and unreliable piece of apparatus. In point of fact, it is possible to-day to buy a small oil circuit-breaker at about the same price as an oil-immersed fuse. Since anybody can close a circuit breaker in the dark, whereas a fuse has to be replaced by a man sent out specially from headquarters, I suggest that at the same price the circuit breaker is the better article. I consider the authors' estimates for the cost of substations to be too high, and I should be glad if they could provide more accurate figures.

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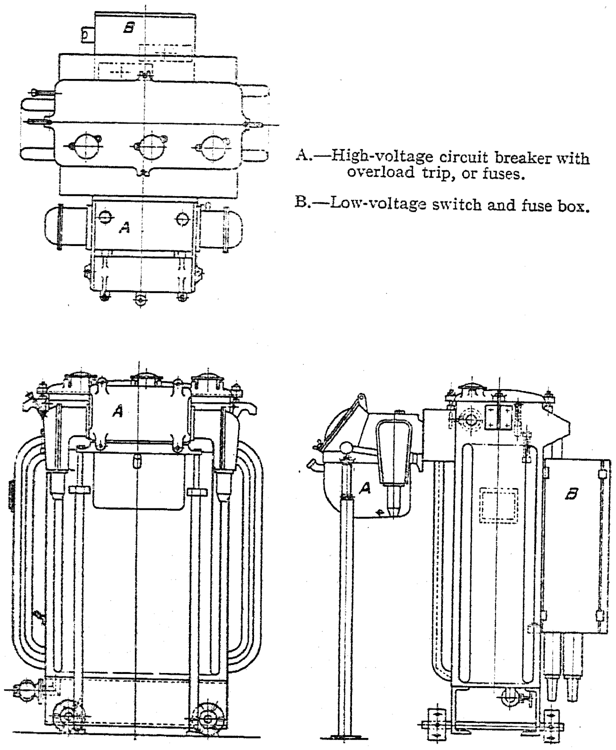
* *Journal I.E.E.*, 1931, vol. 69, p. 194.

Mr. J. P. A. Meldrum: The statement of capital expenditure on page 232 shows that the total expenditure on substations of all types amounts to about 12 per cent of the total outlay. The degree of continuity of supply which is necessary if consumers are to be satisfied is an important factor in the lay-out of a model scheme, and it is necessary to consider the quality of the apparatus that is put into the substations, with a view to obtaining reliability and long life. The authors make a distinction between the various types of substations in that they divide them up into the smaller sizes where continuity of supply is not truly essential, and the larger sizes where it becomes so. Above 75 kVA they appear to consider that absolute reliability becomes essential. In the U.S.A. when rural electrification was booming, supply engineers at first bought the very cheapest equipment they could find, but after a short time they found that this practice did not by any means pay. They have since adopted more expensive and higher-class gear. Turning to the authors' views on the relative merits of circuit breakers and fuses, all fuses have the inherent disadvantage, as compared with circuit breakers, that they necessitate skilled renewal by a member of the supply authority's staff, whose arrival at the substation is inevitably delayed. Further, the actual rewiring of fuses is far from easy in the dark or in wet and windy weather, which causes still further delay in the re-establishment of supply. The majority of faults on an overhead line are of the self-clearing type, and the chief requirement in all protective devices is that after they have operated it should be possible rapidly to restore the service. The only way of doing this is by means of an oil circuit-breaker. A properly-designed oil circuit-breaker will give no more mechanical trouble than an oil-immersed fuse, and the cost of maintenance of either is more or less the same. Many circuit breakers have been in use in kiosks for a large number of years all over the country, and I do not think they have given any trouble such as the authors appear to fear. In addition, with an oil circuit-breaker one can obtain a degree of overload protection which is not possible with an oil-immersed fuse, while a crude form of discrimination may also be obtained. [Mr. Meldrum here showed four lantern slides in illustration of his remarks.] It is not clear what the substation costs given on page 225 really include. I have assumed that they do not include the cost of poles, land, or l.t. cable work, but that they do include the cost of transformers. On this basis, the figures for the smaller size of installations (say, up to 50 kVA) appear to be very nearly correct, while for the 75- and 100-kVA sizes the costs given are at least 10 per cent too high. In the case of the kiosk substations, it is impossible to estimate the cost because the internal equipment is not stated. Assuming that this is estimated on a fairly liberal basis, it should be possible to obtain good-class switchgear and yet keep within a reasonable cost, in view of the revenue which the authors expect.

Mr. A. G. Ellis: The point which perhaps impresses me most in the paper is the sound policy and foresight advocated in the matter of cost to the consumer. Two very sound principles are enunciated on page 203: (*a*) that any drop in the charge per unit to consumers results in an increase of revenue; (*b*) that any increase in the quantity of electricity used should entitle the consumer to expect a lower charge per unit. In the present financially stringent times the potential consumer will not be able to pay a luxury price for electricity, and unless it is cheap he will continue to do without it. According to Figs. 9 and 10, the rates for consumers taking over 3 000 units per annum settle down to an average of 1d. per unit. This is fairly satisfactory, but for consumers taking less than 3 000 units per annum there is an extraordinary divergence of rates, some being twice as high as others. Some of us had hoped that by now the central authority would have done something to make these rates uniform. Cheap electricity has not even reached some of the suburbs, and I think a great deal has to be done in this matter before satisfactory progress will be made. A financial policy such as that advocated in the paper is essential if development in this direction is to be speeded up. Can we assume that the mean curves drawn in Figs. 9 and 10 give the rates to be expected for the various consumers whose energy consumptions are plotted as abscissæ? Apart from the interest of these matters to the consumer and the supply authority, there is the manufacturer's side of the question. Both switchgear and transformer manufacturers are interested in the probable rate of growth of electricity consumption, and it would be interesting if the authors could make a forecast of this, or at least give their opinion of the following figures at which I myself have arrived. We shall soon have about 7 million kVA of main " grid " transformers distributed over the country. What will be the total capacity of distribution transformers ultimately connected to them? It is doubtful whether the ratio of distribution transformer capacity to main capacity in other countries can be taken as a guide for Great Britain. Assuming the value of $2\frac{1}{2}$: 1 for this ratio, one arrives at a figure of $17\frac{1}{2}$ million kVA for the ultimate capacity of distribution transformers in the country. Taking an average size of 100 kVA for these and a " ten-year plan," one arrives at a demand of 17 500 transformers per annum. This big number could easily be turned out by only two of the larger transformer makers in England. The manufacture of transformers is largely a function of the quantities involved, and the figures mentioned are small so far as real mass-production is concerned. In the U.S.A. the two largest manufacturers have actually turned out from 5 000 to 6 000 distribution transformers per week. In such quantities, of course, they can get the costs down to a low level and still make a profit. On the most optimistic estimates we shall never approach such figures as these, especially when we consider the number of transformer makers and the potential manufacturing capacity of the country. What we have to concentrate upon in the small transformer problem, therefore, is the question of standardization. We have been making efforts at this for many years, but have been hindered by the special requirements of many of the supply undertakings and consulting engineers. Largely due to the efforts of Mr. Fennell, the Overhead Lines Association are now endeavouring to get the supply undertakers, especially those concerned with rural work, to standardize their requirements for small transformers. The load factor of the average rural transformer is very low, i.e. it is possible to install a much smaller transformer than is actually required for the peak load. The authors suggest that they would accept 25 per cent less than the B.S.I. rating. While this is on the right lines, the difficulty is that if one installs a transformer for the average duty the voltage regulation on peak loads becomes a serious matter. I suggest that it is rational to fix the nominal or normal voltage at half load, so that at full load one has a voltage-drop equal to half the inherent voltage-drop of the transformer, and at no load a voltage-rise equal to half the inherent drop of the transformer. This renders practicable transformers with a 3 to 4 per cent voltage regulation. It has been suggested by a supply engineer concerned with rural electrification that a transformer tap regulator automatically operated with only two steps—say, for normal voltage and 5 per cent below normal voltage—would meet many of the requirements of rural districts. Such an equipment could be made quite cheaply. Mr. Norris has suggested putting in regulators and thus saving copper on the lines. This is a practice which many engineers have already been driven to adopt through force of circumstances. Naturally if a voltage regulator could be installed at a lower cost than that involved by the extra mains necessary, this would be the right solution. Hitherto it has been impossible to purchase on-load voltage-regulating gear for a transformer up to 11kV under about £200. To-day it is quite possible to obtain such equipment for less than half this amount, and for less than the cost of an induction regulator. These factors may change the complexion of the problem of voltage regulation, especially if the authors' proposal to use iron wire for some of the overhead lines is adopted. I support the authors when they urge the use of 11 000 volts for standard distribution, because the costs of the transformer and switchgear are practically the same for any voltage up to that figure. However, I do not think we should overlook the fact that the 33 000-volt small transformer only costs 33 to 50 per cent more than the 11 000-volt type. As regards the somewhat vexed question of the standardization of terminals, we have for years been required to fit various types of terminals to suit individual ideas. It is necessary to standardize, and at the moment the choice is mainly between cable tails and porcelain-clad terminals connected direct to the lines. I recently examined this question in relation to practice in New Zealand, where a great deal of rural electrification has been carried out. There is a slight preference over there for porcelain terminals which point upwards. I regard these as the best standard type for 22 and 33 kV, but for voltages up to 11 kV I prefer cable tails. Most of the supply systems seem to be worried by birds and the provision of the necessary "bird clearance." A porcelain terminal can easily be shielded by putting an inverted "flower-pot" of porcelain or moulded insulation on the top of the insulator, and I have found this idea simple and satisfactory. In the schedule of costs on page 225 the authors state that the 50-kVA installation costs £92 and the 75-kVA £212. Why is there such a big difference in the cost of these relatively near sizes? Is it due to the cost of mounting the transformer on the plinth, and the extra run necessary for the cables? If so, there is no reason why one should not mount transformers up to 100 kVA on a platform on the pole. A further cheapening of the substation can be effected by combining the transformer with the l.t. and h.t. switches and fuses or circuit breakers, as shown in Fig. L.



A.—High-voltage circuit breaker with overload trip, or fuses.

B.—Low-voltage switch and fuse box.

FIG. L.—Outline of 100-kVA 6 600/400-volt 3-phase 50-cycle transformer fitted with switch and fuse boxes.

Mr. O. Howarth: The figures given towards the end of the paper depend to a large extent on the curve shown in Fig. 4. Is that curve based on actual experience, or is it an estimate? It seems to me that to obtain 20 per cent of the possible connections in the first year, and at the end of the sixth year to have made 74 per cent of the possible connections, is rather a tall order. Referring to Figs. 9 and 10, the authors mention with surprise that in urban areas the costs are slightly higher than in rural areas. Possibly this may be due to the much greater proportion of shop lighting in urban areas. Shop lighting cannot be dealt with by a supply authority so cheaply as household lighting, owing to the incidence of demand and the restricted hours of use. Referring to the question of the fixed charge, it occurs to me that as the rateable-value charge is based on the rating assessment, it therefore has no rational basis.

Mr. G. L. Porter: In Section 8 the authors make a bold attempt to evaluate the effect of price upon consumption. These quantities are, of course, related, but care must be taken to distinguish between cause and effect. The authors have compared the average figures of price and consumption of 221 undertakings, and they apparently assume that if one undertaking reduces its average price to that of another the figure of units per consumer will similarly alter. Unfortunately this assumption ignores the effect of the *shape* of a tariff on the average figures obtained. A high average figure of units per consumer may be due not to the fact that low prices encourage maximum use, but to a tariff of such a shape that the naturally small consumer is kept off the mains. On the other hand, an undertaking may consider that its duty as a civic body is to give as widespread a supply as possible, and it may therefore encourage the connection of unremunerative small consumers (with a corresponding overcharge to the others) so that the average taken per consumer is low and the average price therefore high. Table 19 is of special significance in this respect. Here the figure under the heading of "running" charge is the price per unit necessary to supplement the "service" charge, and its amount is evidence of the correctness or otherwise of the latter. It is very striking to note how an insufficient service charge results in a low figure of units per consumer, and how too high a fixed charge—by discouraging small consumers—results in a high average consumption. Lighting and other forms of domestic load have different characteristics. Any house having electric light is usually without other forms of illuminant, and a fixed charge covering the lighting demand could reasonably be based upon the size or even the rateable value of the premises. This state of affairs, however, does not obtain in the case of other forms of domestic load, and the cost of their additional demand cannot be included in the fixed charge. It is usually collected with the running charge, the price per unit being correspondingly greater than the actual cost of production. It will be seen that we are here re-introducing the very thing that the 2-part tariff was intended to avoid, i.e. the collection of a mixed demand and running cost by means of a flat rate per unit. Some undertakings avoid this by stepping the unit charge so that the whole tariff becomes a fixed charge plus a block tariff on units consumed. It would certainly appear much simpler to make the tariff purely a block tariff, the size of block being determined by considerations such as the size of premises on which the first item of the present tariff is based. While such a tariff is not quite as simple as the plain 2-part tariff, it has two very clear advantages; first, that it encourages long-hour use of current, and secondly, that as the demand charge on the lighting is spread over a block of units it ceases to have the objectionable form of a fixed charge. What is urgently required is an investigation of the manner in which the net demand of a given size of house varies with the number of units taken per annum. If the load factor is sufficiently constant, the plain 2-part tariff is justified. I am sorry that the authors have not found room in the paper for some consideration of means of voltage regulation. From their own figures it would appear that in substations (*d*) to (*g*) the installation of regulating apparatus would allow of a reduction in the capital cost of distribution of at least three times the cost of the regulating apparatus. In addition, there would be a saving in interest charges, as owing to the growing nature of the load the expenditure on the regulator could be postponed until the size of the load had increased to about 50 per cent of the ultimate figure.

Mr. A. B. Mallinson: I do not share the authors' views as to the reliability of spur lines. I recently changed over a public institution in Warwickshire from its own to the public supply, since when there has practically never been a month free from interruption. The breakdowns of the supply have varied in duration from a few minutes to 36 hours. Had it not been that the battery and gas engines of the old plant were retained, the institution would several times have had to rely on candles. This, I suppose, is what we must expect with a 99 per cent reliability of supply, instead of what our supply engineers have previously aimed at, i.e. 100 per cent reliability. Turning to the question of tariffs, at the institution to which I have referred the tariff is in the form of a fixed charge based on the maximum demand, together with a unit charge governed by a coal clause. The lay members of the visiting committee find it very difficult to grasp the technical details of this system of charging; I suggest that if we are to have 2- or 3-part tariffs these should be intelligible to the lay mind.

Mr. T. W. Ross: Referring to the question of continuity of supply, the authors make no mention of the reclosing circuit breaker, a device which I consider to be particularly well adapted to rural electrification. Experience shows that probably 90 per cent of the faults on rural lines are of a transient nature, and will allow of the circuit breaker being reclosed almost immediately after it has tripped. If, therefore, an automatically reclosing circuit breaker were employed the supply would, in most cases, be restored with very little inconvenience to the consumer. Another aid to continuity of supply is the arc-suppression coil, which is so largely used on the Continent. It may be that these coils are not suitable for all networks, because of the relatively small electrostatic capacitance of the lines, but during a recent visit to Germany I found that they were installed on practically all lines on which the charging current was greater than 5 amperes. From the operating statistics of the supply authorities using such coils we learn that from 75 to 90 per cent of the insulator flash-overs are cleared without the tripping of a circuit breaker. On the rare occasions when a dead earth takes places the system is operated in this condition until such time as it is convenient to remove the fault. It should be noted that earth-fault protective relays are not usually installed on systems protected by the arc-suppression coil.

Mr. G. F. Sills: The authors refer to oil-immersed switch-fuses, and I should like to state that there are triple-pole and, alternatively, three single-pole type oil-immersed switch fuses in the same tank, on the market. Do the authors consider that the single-pole type fuse is better than the triple-pole type? In the latter, if one fuse blows, the three phases are put out of circuit. For rural supply, in view of the possibility of troubles associated with branches it would appear to be better policy to have an oil-immersed switch-fuse of a type that only isolates the phase involved, and does not interrupt the supply to those consumers who are fed from the other two phases. I believe glass insulators to be cheaper than porcelain for low voltages and the lower high-tension voltages, and I understand that experiments are being carried out in this country with a view to the use of glass insulators for rural supply. It might be advisable to concentrate on this form of insulator and get our manufacturers to take them up. As rural electrification becomes more widespread it might pay to distribute more frequently at 3 300 volts. The extra cost involved is exceedingly small, and many advantages are associated with the use of the higher voltage. I think it is a mistake for the rural user to expect 24 hours' supply every day of the year. He should realize that if he is to have a low tariff he must be prepared to be without a supply for periods of two or three hours a few times a year. It is rather a different matter, however, in districts where incubators are used in large numbers, as in this case I believe the supply must not be off for more than 20 minutes. The question of regulation is becoming more and more prominent, and there are two aspects to be faced when a low voltage is given to the consumer. (*a*) The consumer considers that he is not getting a proper service if he is not given the right voltage. (*b*) The supply authorities lose units. If we could get users to standardize requirements for small transformers, it would help manufacturers in this country. At the time of the Tokio earthquake a British firm was offered an order for about 15 000 pole-type transformers on condition that they were delivered quickly; but owing to the comparatively small number of pole-type transformers used in this country it was impossible to meet the requirements for delivery, and the order went to America.

Mr. P. Clegg: On page 197 it is stated that "the revenue to be derived from the various sources other than domestic is most material to the successful issue of any rural electrification scheme." While I agree with this, it is important to bear in mind that so far as real rural electrification is concerned it is difficult to obtain anything other than farm and domestic loads. Where large power consumers are available these have in many cases already been supplied, and have been the reason for the rural electrification that has been carried on up to the present day. On pages 188 and 189 the authors state that for their Model Scheme they have been careful not to anticipate too high a figure for power units sold. They expect 33 per cent of the total units sold for the first year, and 43 per cent for the sixth year. To my mind these figures are very high. On page 201 the authors assume a price of £3 5s. per kW + 0·20d. per unit, at power factors ranging from 0·85 to 0·9. I can agree with the £3 5s., but I am afraid the figure of 0·2d. per unit is a little lower than most engineers can anticipate. I am able to state from personal knowledge extending over the last three or four years that no supply authority in the Yorkshire area has been able to get down to 0·2d. per unit during that period, except on a block system in which there is a high charge on the first block. With regard to the revenue and expenditure account (page 227), the distribution costs appear to be much lower than those generally prevailing on town supplies, although it is a well-known fact that the distribution costs of rural supplies are higher, per kilowatt sold, than the corresponding figures for town supplies.

Mr. G. H. Sammons: I do not think the consumer's point of view has received sufficient attention, either in the paper or in the discussion. Much has been said of prices of apparatus and of tariffs, but what of the nature of the supply the consumer will receive? Leaving out the question of breakdowns, which on all overhead systems are too frequent, the quality of the service is a question of voltage regulation. Referring to Fig. 11, we find that the substations of the Model Scheme are situated 2 miles apart, which means either that low-tension distribution will have to be undertaken up to 1 mile from each substation or that some houses will be beyond the range. The usually-accepted limit for low-tension distribution is about 800 yards, and I should like to ask the authors what kind of voltage regulation will obtain at the extreme end of the line. It is very certain that the voltage between the phase wire and the neutral wire will vary within very wide limits, due to any load out-of-balance, and the regulation of any such variation by e.h.t. methods is impossible. In my own experience I have known the voltage to fall from 230 to 200 volts when a 3-kW fire was switched on in a house supplied by an overhead line about 1 000 yards long. Further, it should be noted that when the voltage on one phase falls, consumers in the vicinity whose supply is connected to another phase receive a corresponding increase in voltage, provided that the out-of-balance is maintained. It is no exaggeration to suppose that under such conditions the voltage at a consumer's terminals is likely to vary between 260 and 200 volts, and I have seen voltage record charts showing such a variation. Increasing the copper cross-section will not improve matters very much, as the chief cause of the voltage-drop is the spacing of the conductors. In order to solve this problem it is necessary to reduce the length of low-tension lines, which can be effected by having more frequent substations. I should like to ask the authors why they do not advocate the use of double-wound transformers giving a low-tension local supply and an intermediate high-tension supply, together with more frequent substations. This system is already in operation in the south-western counties. Why is it not possible to install two substations at the extremities of a village, rather than one at the centre? If this were done an alternative supply would be provided to each isolated system and the range of effective and satisfactory low-tension distribution would be increased.

Mr. G. L. E. Metz (*communicated*): In the theoretical lay-out (Figs. 11 and 12) of the Model Scheme, the supply to each 100-square-mile area is shown as being dependent upon a single 33-kV overhead line, the failure of which would leave the area without a supply. Will the Scheme stand the cost of duplicating the 33-kV feeders or of providing a 33-kV ring, or do the authors consider such a precaution to be unnecessary? From the interconnected network shown in Fig. 12 it would appear that a fault such as a broken line anywhere in the outer 11-kV ring might blow the fuses protecting each of the four radial feeders, thus making the whole area "dead." I am aware that this difficulty could be overcome by sectionalizing the area under normal conditions, so that a fault in any one section would only affect one radial feeder. I should like to know whether this method would have a considerable effect upon the regulation of the system as a whole, and whether it would also tend to be uneconomical as regards the amount of copper necessary. Since the authors do not intend to use circuit breakers anywhere on the system, it would be interesting to know whether they regard the possibility of faults of this kind as sufficiently important to merit special attention in designing their scheme. If so, what methods are used to overcome them?

Mr. E. T. Norris also took part in the discussion. The substance of his remarks will be found in the report of the discussion before the Institution—see page 237.

Mr. J. Solomon (*communicated*): I should like to ask the authors whether they could present some figures giving the costs to date of the Bedford and Norwich demonstration schemes. Such figures would enable a comparison to be made between the Model Scheme and actual schemes of rural electrification now in process of development.

[The authors' reply to this discussion will be published in a later number of the *Journal*.]

SOUTH MIDLAND CENTRE, AT BIRMINGHAM, 18TH JANUARY, 1932.

Mr. W. A. Coates: In previous discussions on the paper various speakers have made estimates of the quantities involved in a nation-wide rural electrification project. It seems to me that these have been considerably overdrawn. The maximum area likely to be involved in such a scheme can be taken from Table 5, the forest and rough lands being neglected. This gives 50 394 square miles, or 126 of the authors' 400-square mile units. I presume the authors would assess the population density in these 50 000 square miles as 150 per square mile, or possibly rather more. We can thus refer directly to the capital estimates on page 226, and get the following rough totals.

11-kV lines of all classes ..	..	£19 085 472
Step-down equipments ..	..	5 177 592
Low-tension lines ..	..	6 977 124
Services	..	2 401 560
Meters	..	2 401 560
		£36 043 308
Contingencies ..	5 per cent	1 802 165
Total estimated cost ..		£37 845 473

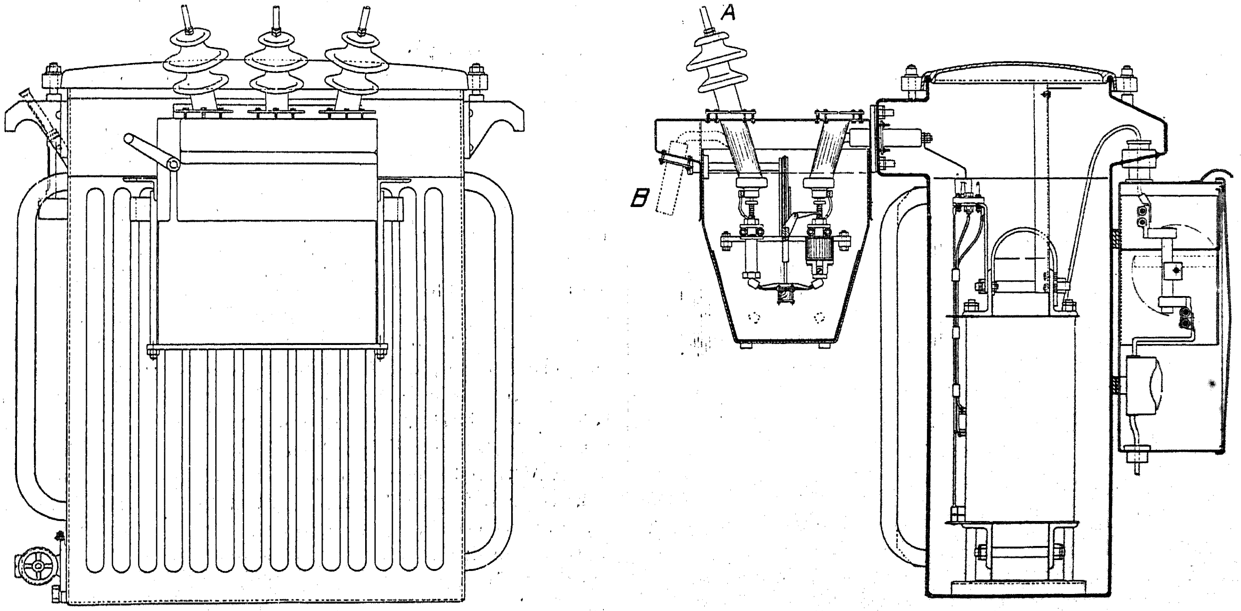


FIG. M.—Three-phase distribution transformer unit fitted with high-voltage circuit-breaker with overload trip and low-voltage switch and fuse.

A. Terminals of high-voltage switch for bare connection to line.
B. Terminals of high-voltage switch for cable connection to line.

These figures, of course, take no account either of the secondary transmission systems (at, say, 33 kV) which will usually be necessary to interlink the grid system with the 11-kV lines sketched by the authors, or of the 33/11-kV transformers and substations. From the table on page 226 we can get also the following approximate estimate of the 11 000/400/230-volt transformer requirements.

48 384 units of	5 kVA, aggregating	241 920 kVA
2 016 units of	15 kVA, aggregating	30 240 kVA
3 428 units of	25 kVA, aggregating	85 700 kVA
3 024 units of	50 kVA, aggregating	151 200 kVA
1 512 units of	75 kVA, aggregating	113 400 kVA
504 units of	100 kVA, aggregating	50 400 kVA
1 008 units of	200 kVA, aggregating	201 600 kVA
504 units of	300 kVA, aggregating	151 200 kVA
126 units for industrial use, at 3 300 kVA ..	.. ..	415 800 kVA
	Total estimated capacity ..	1 441 460 kVA

In his contribution to the Manchester discussion* on the paper Mr. A. G. Ellis mentioned that the Central Electricity Board will install about 6 000 000 kVA of 132-kV transformers, and he applied a multiplying factor of $2\frac{1}{2}$ to get a rough idea of the total capacity of all the distribution transformers needed, including urban and suburban areas. As the grid system is a busbar rather than a system of feeders, the usual rough rules of proportion are not entirely applicable. Considering rural work only, I suggest that my figure of $1\frac{1}{2}$ million kVA should be divided by $2\frac{1}{2}$ to get an idea of the necessary capacity of 33/11-kV transformers. This gives us about 600 000 kVA, which with switchgear might be worth, say,

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* See page 455.

£2 500 000. On the face of it, one would expect that an expenditure of between 50 and 60 million pounds would cover our national rural reticulation needs. I believe that such an expenditure would be a much better investment than the wholesale electrification of railways, which has been stated by the lay Press to be the sole hope of salvation for the "grid" scheme. Before any national step of this nature is taken, however, a great change of opinion is necessary in respect of what constitutes sound yet economical engineering. The authors refer to the need for standardization in the interests of lower transformer prices. In these days of cut-throat competition in this particular field, their comment reads almost like satire. However, quantities such as make up my $1\frac{1}{2}$ million kVA of distribution transformers fall far short of the figures necessary for a real mass-production basis of manufacture, unless perhaps the work were carried out in a single year by one factory. The works with which I am associated could do the whole job in 10 years, without any changes in the factory whatever. In actual practice, of course, the work would be spread over several years and many factories; in any case, no maker could take on a contract of this sort, since it would be non-recurrent and would merely have the effect of losing him his place in the general market. Standardization of ratios, terminal arrangements, etc., is highly desirable from all points of view, even though it would lead to only a slight reduction in costs. It seems to me that the costs of line construction must be cut down considerably. Fig. M shows a substation equivalent to the authors' Fig. 27, but incorporating an oil circuit-breaker with its isolators mounted on the "H" poles. The loading on the poles is actually less than with the fuse arrangement. A still better arrangement is that of Fig. N, which incorporates what has been christened the "transwitch" arrangement. The details of this are shown in Fig. O. The high-voltage oil circuit-breaker and the low-voltage distribution switchgear are metal-enclosed and mounted directly upon the transformers, without any exposed intermediate conductors. If this method of construction be adopted lines can be tapped at any pole, since only the isolators and a cable pot-head are carried thereon. Apparatus such as that described above is to be had from more than one maker, and to my mind it should be employed in preference to fuse devices on all except spur-line services. [Mr. Coates also referred to the progress of rural electrification in New Zealand. The substance of his remarks in this connection will be found in the report of the Manchester discussion (see page 454). Arising out of these remarks, he commented that post-office facilities and the ready granting of wayleaves were points of major importance tending to facilitate work in the newer countries, and were the outcome of a national appreciation that electricity is just as necessary as telephone and telegraph services. He suggested that the Institution should put itself at the head of an industry-wide effort to bring about similar conditions in Great Britain. He said that the prosperity of every member is locked up in the prosperity of our supply undertakings.]

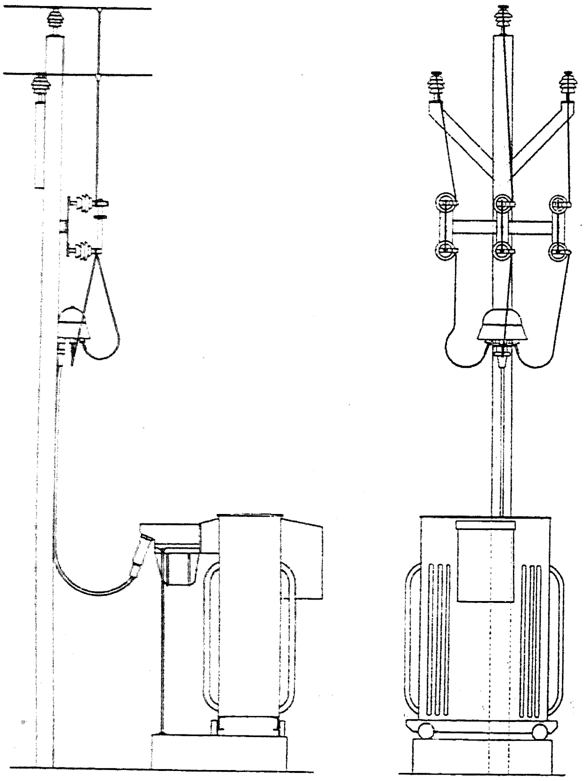

FIG. N.

Mr. H. Joseph: In view of the inevitable development of an all-electric domestic load the problem of electricity supply is difficult enough in comparatively densely populated residential areas, but in the sparsely inhabited districts dealt with by the authors it is infinitely greater. Realizing that a road full of all-electric houses will result in enormous loads, I believe that the former problems can only be solved by high-tension distribution, grouping consumers by means of short lengths of low-tension cable on isolated transformers so as to reduce transformer capacities as the result of the diversity factor of the small group. The authors propose to employ low-tension distribution in rural areas, and they base their calculations for a model scheme of distribution on loads per consumer which I regard as far too light. In Table 23 they choose a 15-kVA transformer to deal with 12 consumers and a 5-kVA transformer for an isolated farm. In Table 27 they anticipate being able to deal with 6 446 consumers with a maximum demand of 6 592 kW at the end of six years; in Table 28 very similar results are anticipated. I suggest that all the above figures are far too low. If after 6 years we have not progressed some considerable way towards the attainment of the all-electric house, we shall have very little to show for all the efforts that are being made by the British Electrical Development Association and the industry generally. Let us consider the isolated consumer with his 5-kW transformer. We may imagine that it is a cold winter and that a child is ill in a bedroom heated by means of a 2-kW radiator. Its mother is cooking the midday meal, and using, say, 3 kW. The rest of the family are in the sitting-room waiting for it to be served, and they have a

3-kW fire full on. In the dining-room a 2-kW heater is being employed to get the room warm. Even assuming that the water heater is switched off and that no use is being made of the various other electrical appliances which may be installed, the total load is 10 kW at a very modest estimate. I therefore suggest 15 kVA as the minimum size of isolated transformer which should be installed. One might, of course, put in a 5-kW transformer, base the fixed charge on the transformer capacity, and install a circuit breaker which will insert a resistance when the capacity of the transformer is exceeded. Such a system, however, prevents that free and unrestricted use of the supply without which electricity will never come into general use for domestic purposes. Similarly, as regards the authors' suggestion of a 15-kVA transformer for 12 consumers, they must take a very pessimistic view of the future if they think that in 6 years' time this will be adequate. The problem of rural distribution appears to be a difficult one. If the objects at which we aim are to be attained it would appear that some compromise between h.t. and l.t. distribution is likely to be the solution. If distribution is to be entirely at high tension and each consumer is to have a separate transformer, this will have to be of

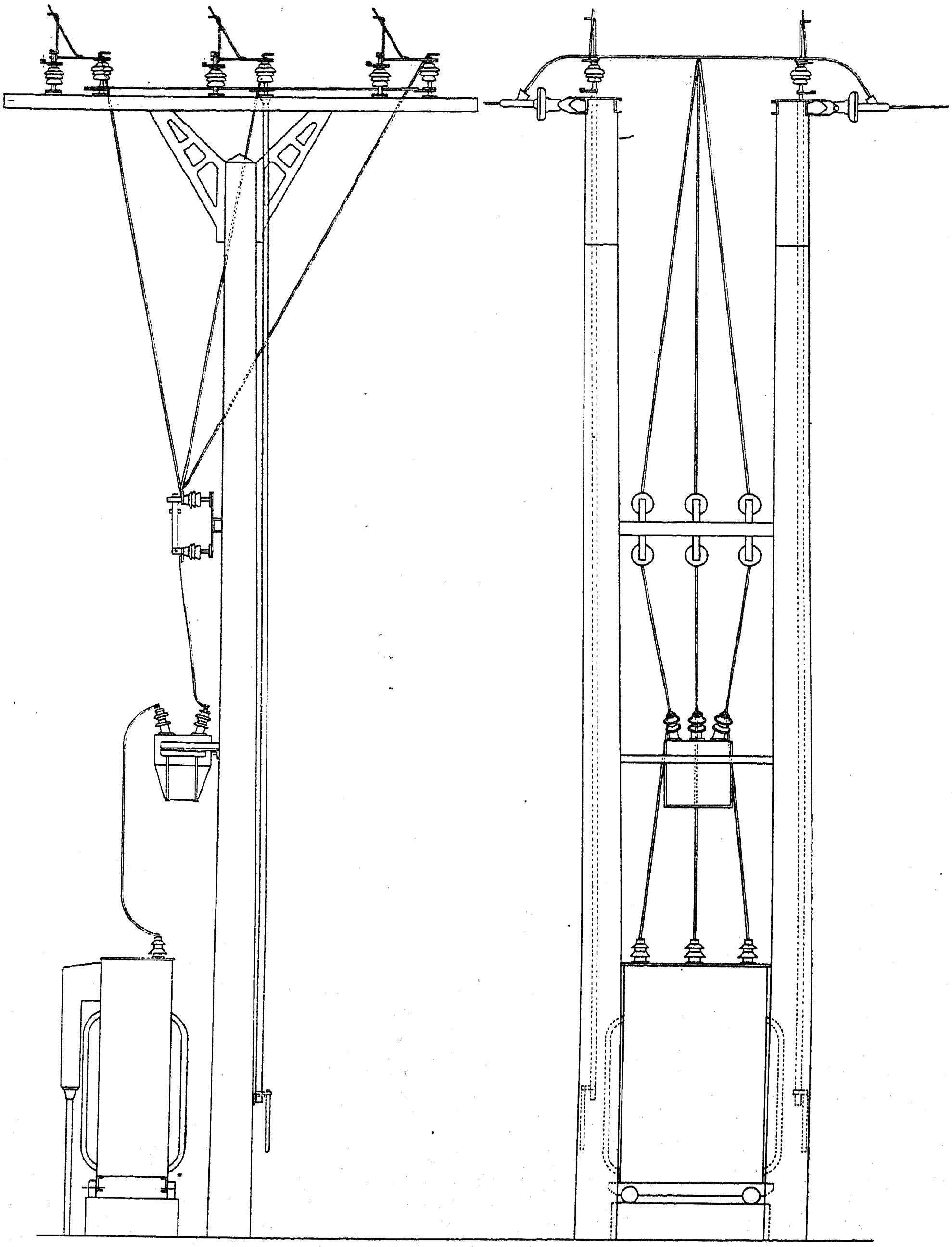

FIG. O.

large capacity. Can the authors say which would be cheaper, isolated transformers and high-tension distribution or small groups joined by l.t. distributors? The foregoing applies to isolated farms; in the villages there will be some roads the dwellings in which could be conveniently grouped on a series of isolated l.t. networks. If we really believe in what we preach it is a waste of money to lay down a complete l.t. network on the lines which have been followed ever since public supplies have been available. The loads which will have to be dealt with in the near future will make such networks obsolete both in urban districts and, to a less degree, in rural areas.

Mr. G. R. J. Parkinson: I propose to refer only to the first portion of the paper, which deals with general considerations. The authors describe a Model Scheme based on certain model conditions, selected from the statistics of a large number of existing undertakings. Before embarking on any scheme of rural electrification the individual conditions must be considered, however, and each scheme must be judged on its merits. I regard an assumption of average conditions as very dangerous, as is evidenced by the figures given in Table 9. Taking only the first two items—small cottages and larger cottages—in the case of the Sussex villages the weekly revenue varies from 4s. to 5s. 8d. in small cottages, and 6s. to 8s. 1d. in larger cottages; whereas for Worcestershire villages it is from 10d. to 1s. 1d. in small cottages, and 1s. 3d. to 1s. 4d. in larger cottages, i.e. four or five times as much in Sussex as in Worcestershire. Although it might be suggested that this was due to better development in Sussex, I know from personal experience that the company responsible for the supply in Worcestershire have carried out an extensive campaign of canvassing and propaganda, and I can only assume that the difference is due to differences in the mode of life or class of the consumers in the two counties. Thus if a scheme based on average conditions were highly successful in the one county, it would be a hopeless failure in the other. The authors recommend 400 square miles as a suitable area, and assume that at the start no electricity supply is available; but if we exclude sites containing large areas of mountains, moors, bogs, and forests, I am afraid it would be difficult to find many suitable sites of this area in England in which there has not already been considerable electrical development. As an example, take the 400 square miles between Wolverhampton, Stafford, Burton, and Tamworth. Except for a number of towns on the borders, this is mainly rural. This area may be a bad example, but it is a good illustration of my argument. The area contains no less than nine towns with independent electricity supply authorities, viz. Wolverhampton, Walsall, Tamworth, Lichfield, Cannock, Burton, Stafford, Rugeley, and Sutton Coldfield, and I am afraid that the development of the electric supply in this area, independent of the existing authorities, would not be a remunerative proposition. I suggest that in this and many other cases, the most suitable method of developing the rural electric supply would be for each of the existing undertakings to be made responsible for electrifying 40, 50, or 100 square miles of rural area immediately adjacent to their existing supply areas. The additional area could be developed with very little addition in the way of general establishment charges. Further, even if there were a small loss on the rural supply during the early stages of development, such loss, although a serious matter to an independent rural authority, would have an inappreciable effect on the costs of the whole undertaking. With regard to Table 19, the authors calculate an average charge of £5·05 per annum per consumer, plus a running charge of 0·93d. per unit; they appreciate that such a charge would be quite impracticable in the case of very small consumers, but I am unable to gather from the paper their method of arriving at the graduated service charge. As regards the authors' comments on Table 17, there seems to be some confusion between cause and effect. I do not think that a drop in charge will necessarily result in an increase of revenue. Might we not equally say that the supply authorities had reduced their charges on account of the increased consumption? While the method of arriving at the curve shown in Fig. 9 is interesting and ingenious, in view of the great departure from this curve displayed by the dots giving the actual revenue I do not think there is sufficient justification for assuming that the curve represents a true average.

[This discussion was adjourned until the 8th February.]

South Midland Centre, at Birmingham, 8th February, 1932.*

Mr. E. F. Hetherington: I consider that the authors are too optimistic as regards their estimates of the cost of erecting the overhead lines and the revenue to be derived from supplies in rural areas. A considerable sum of money has been laid out by the Central Electricity Board on the "grid" scheme, and it is only by pressing forward with all development work likely to prove financially sound that the requirements for electrical energy will be increased and the Board thus enabled to utilize fully the capital which has been expended. Quite apart from these considerations, however, it is high time that residents in rural districts were provided with the amenities available in the towns. It should also be recognized that a cheap and abundant supply of electricity in rural areas would tend towards the shifting of industries from the towns to the healthier conditions of the countryside, with the concomitant reduction in operating costs due to cheaper land, lower rates, etc. I agree with the authors that sporadic extensions of electric lines should be discouraged and that areas as large as possible should be tackled on the basis of definite schemes. It is, of course, a comparatively simple matter to carry lines from large towns into the surrounding rural areas; in many cases where this has been done it has been possible to supply electricity in these areas at somewhat lower rates than would otherwise obtain, due to the fact that the general establishment charges can be spread over the rural area and the town simultaneously. The financial problem, however, is not such an easy one where purely rural areas have to be taken in hand and made to pay their way without the advantages either of a contiguous town supply or possibly of one or two fairly large industrial consumers, the revenue from whom would go a long way towards paying the standing charge on main transmission lines. It devolves on such concerns as joint electricity authorities and the power companies to electrify the less remunerative areas. The difficulty with which we are all likely to be faced in the near future as rural areas grow and become contiguous to one another, is the wide diversity in tariffs under which various schemes are being operated. A difference in tariff between two towns fairly near to each other is not a serious matter, as their boundaries are separated by the intervening country. Rural areas may, however, be definitely contiguous, and one is then faced with the anomaly that two villages—possibly under the same local authority—are supplied by two separate undertakings at different rates. This is liable to cause considerable difficulty, particularly in the minds of the less sophisticated country folk, and I think it very desirable that there should be some movement towards uniformity of tariffs for rural areas. It may not be possible, due to local conditions and the distance the energy has to be transmitted, to make prices uniform, but the form of tariff should at least be the same throughout. Engineers responsible for the development of rural areas continue to find it difficult to obtain the necessary wayleaves for the transmission lines. Almost without exception, people living in the country are anxious to obtain the benefits of a supply of electricity, but they often raise all kinds of objections when they are asked to consent to the carrying of overhead lines across their land in order to make it possible to give them that supply. The cost of obtaining the wayleaves is by no means an inconsiderable charge on the capital cost of a large distribution scheme, and I do not think the authors' estimates make sufficient allowance for this work. They recommend that an area of not less than 400 square miles should be considered for electrification purposes. I think that a model scheme should approximate as closely as possible to the actual facts, and there are not many undeveloped districts in this country having as large an area as 400 square miles. Very much smaller areas have been, and indeed are being, successfully electrified. On page 191 the authors make reference to the fact that the Regulations issued by the Electricity Commissioners offer on the whole no impediment to the selection of suitable materials. While I am on the whole in agreement with this view, I would state that the Home Office officials are beginning to take an interest in the equipment employed in rural electrification. As regards the revenue to be obtained from various classes of rural property, I cannot help feeling that the "typical" examples given on page 198 have been specially selected. It seems almost inexplicable that a 3- or 4-roomed cottage, presumably occupied by an agricultural labourer, should be capable of yielding a revenue of £8 to £12 per annum. I am in agreement with the authors' contention that no rural development scheme can be successful without the provision of such facilities as assisted wiring, hiring, and hire-purchase service, but I am not in favour of the suggestion (page 199) that it might be wise to consider the possibility of charging free wiring to capital account. The business of an electricity supply undertaking is to give a supply of electricity to all its consumers at the lowest possible cost, and the considerable addition which free wiring would make to the capital charges would inevitably result in a higher charge for electricity all over the area. It appears to me to be unfair that consumers who meet the cost of their own wiring should be called upon to pay higher rates for electricity in order to finance the free wiring of smaller properties. I am interested in the graphical representation (Fig. 9) of the relationship of the units sold per consumer to the cost of electricity, but I do not understand why the authors should be surprised that the results follow a hyperbolic curve. Am I not right in assuming that all supply and demand curves must be hyperbolas in view of the fact that with a fixed income a more or less fixed proportion of that income is available for each service required? Besides this consideration, however, the fact that the curve is almost a rectangular hyperbola indicates that the relative proportions of lighting, heating, and power units are fairly constant. I agree that reduced prices tend to increase consumption, but is not the result indicated in Fig. 9 partly the effect of 2-part tariffs? In short, does not increased consumption tend to reduce prices to a greater extent than reduced prices cause an increase in consumption? In the last paragraph on page 206 the authors suggest that in the earlier days of construction it may appear more lucrative to depart from the general framework of design, but that this is bound to react to the detriment of the whole scheme. I agree generally with this principle, but would point out that it is quite possible to plan a distribution scheme with a view to deferring capital expenditure in many directions until the business grows, without in any way detracting from the completion of the scheme as originally intended. For instance, it is perfectly practicable to commence supply in certain places by means of pole transformers where ultimately a suitable substation will be constructed, and in many cases I have found it possible to operate at 11 000 volts lines designed for 33 000 volts, thereby deferring the capital cost on main substations until the load warrants it. The diagrammatic lay-out of a model rural area (see Fig. 11) is interesting, but the authors do not appear to have contemplated the interlinking of the four main areas. According to the diagram each area is entirely dependent on a 33 000-volt main transmission line, and I suggest that it would be very much better for the areas to be interlinked so that if one of these lines broke down, supplies could be given by an alternative route. I should like to refer here to the desirability of devising cheap and satisfactory means for tapping 33 000-volt lines for giving supplies to comparatively small areas or isolated factories along their routes. In the area for which I am responsible, several cases have arisen where a main 33 000-volt transmission line passing between one town and another could with advantage be tapped, but the revenue to be derived from the tapping point is insufficient to justify the construction of what one might call a first-class substation. It is, of course, quite possible to tap such lines by means of switch-fuses, but as the main transmission lines are usually carrying important supplies it is essential that they should be adequately protected from any faults which may occur at the tapping point. What seems to be required is something between the ordinary switch-fuse and a high-class circuit breaker of adequate rupturing capacity. I believe that several switchgear manufacturers are working on this problem, and it is to be hoped that they will soon evolve something on the lines I have indicated. I think it would be a very short-sighted policy to erect conductors of so small a cross-section as No. 8 S.W.G., as indicated in Table 24. Such circuits would be unsuitable for a cooker load, and if only one consumer desired to install a cooker it would be necessary to put up heavier conductors. A somewhat similar argument also applies to the suggested use of 5-kVA transformers for certain villages, as such apparatus would be inadequate if one or two cookers were installed. The statement of comparative costs of copper and steel-cored aluminium lines given in Table 25 shows a bias in favour of the latter. Quite recently the price of copper has been as low as £45 per ton, at which figure there is very little difference between the cost of copper lines and the authors' figures for steel-cored aluminium. Apart from this, however, sufficient allowance is not made for the fact that on steel-cored aluminium lines the conductors are strung up at a higher tension and that consequently stronger angle and terminal towers are required. It should also be observed that the wind and ice loading on steel-cored aluminium lines must inevitably be higher due to the greater conductor area. My view is that in actual practice there is very little indeed to choose between the two methods of construction. I prefer copper secondary lines, and am using them throughout the area for which I am responsible. As regards spur lines (page 216) I agree that in many cases it is difficult to decide whether the cost of a spur line to give supply to an isolated consumer is justified. To charge the cost of such lines to the capital account is indeed a doubtful policy, as it does not seem fair to make the cost a charge on the undertaking and thus call upon the consumers in the rest of the area to share the cost of giving a supply to premises remote from the transmission lines. I consider that, at any rate during the initial years of operation of a rural development scheme, spur lines should only be erected where the consumer is prepared to guarantee a minimum annual revenue sufficient to cover the capital charges on them. This can be obtained very conveniently by the adoption of a pole-transformer tariff, under which the consumer pays a fixed sum per quarter per kVA of transformer capacity installed for his special use, plus a low rate per unit as a running charge. Generally speaking, it is possible to erect spur lines very cheaply, as in most cases, owing to the lightness of the load, steel wires and long spans can be advantageously employed, and I think that it is only where long spur lines would be necessary that an undertaking is likely to lose a consumer due to the minimum charge being excessive. Turning to the question of low-tension distribution, I agree that the circumstances are few and far between where it would be cheaper to use underground cables rather than overhead lines for village distribution. It was unfortunate that so much publicity was given to one instance where cables happened to prove cheaper, as this information has become known to a large number of local authorities in rural areas, all of whom would much prefer the villages under their control to be supplied by means of underground cables. The cost of the latter is, of course, only justified in special cases, and I have on a number of occasions experienced great difficulty in persuading rural district councils who have heard of the above case, to accept overhead distribution in the villages in their area. The schedule of costs (page 225) appears to be somewhat on the low side, particularly the figure of £375 per mile for 11 000-volt secondary line. I have no doubt that a perfectly straight line across open country could easily be erected for this figure, but it is inadequate for the average line. The authors do not seem to have allowed sufficient for such contingencies as the additional cost of angle poles and stays, section switches for splitting up ring mains, railway, Post Office, and road crossings, tree felling, and the expenses of making the preliminary survey and obtaining the way-leaves. The figures given in the expenditure and revenue account (page 231) are also too optimistic and do not represent the state of affairs existing in actual practice. The authors' price per unit purchased from the Central Electricity Board is rather low, having regard to the fact that after buying the energy from the grid it will in many cases be necessary to transmit it some distance to secondary feeding points. My view is that the authors have based these figures on a rather better load factor than would actually be obtained in practice. A well-designed and efficiently operated distribution scheme should be made to pay its way by the end of the third year, but I think the authors are unduly optimistic in supposing (page 227) that under their Model Scheme, with a density of 150 per square mile, an actual surplus would be made in the second year. This might be the case if the rural area were surrounded a town where the transmission mains, radiating from the centre, were relatively short, but it could not possibly apply to an area where the energy had to be transmitted any considerable distance. As regards the remark (page 235) that no adequate reasons are apparent why electrification should not, in areas over which powers of supply are held and are not yet electrified, be proceeded with at once, I agree that there is no adequate reason except cost, which is and will remain for some years to come a vital factor in connection with the practicability of such schemes. The paper tends to show that one may embark on rural electrification schemes with very little risk; I think it would have been better if it had clearly indicated the considerable problem which capital cost presents. If this had been done, the paper would have given a much greater incentive not only to supply undertakings but also to the manufacturers of equipment to make every endeavour to devise cheaper means of carrying out the important work of rural electrification.

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* Discussion adjourned from the 18th January.

Mr. T. A. G. Margary: The information given by the authors with regard to the distribution of population throughout Great Britain is interesting, and it would be useful as a basis for calculating the revenue from rural supply were all the rural areas of England being treated as a whole. As it is, there are not many rural areas which are more than a comparatively few miles from an existing electricity undertaking. The authors recommend an area of 400 square miles as the average for an economic rural development scheme, for the reason that in an area of this size there will be sufficient towns and large villages to carry the losses on the overhead lines and plant required for supplying the scattered hamlets and individual farms. In effect, therefore, they are merely giving in fuller detail the statement made by Mr. Herbert Morrison (the late Minister of Transport) that the dwellers in the towns should help their country brethren and contribute towards the cost of rural development by paying a little more for their electricity. On this assumption, the rural area which any undertaking can carry depends entirely upon the size and type of its town load. In some cases the size of the most suitable area will be greater, and in others less, than the 400 square miles proposed by the authors. The whole question of electrical development in rural areas really depends upon whether the supply authorities regard their undertakings purely as business concerns whose object is to secure the largest return for the minimum of capital expenditure, or as a public service which should be given to everyone provided a loss is not incurred. The revenue to be obtained from rural areas must depend largely on the habits of the people. The experience in my own area is that the revenue from the rural inhabitants is very much less than that obtained from similar installations in the town. Our accurate records of some thousands of assisted-wiring installations show that whereas the average number of units in the town is 150 per annum, in the country it is only 81. It would have been much better, therefore, if in Tables 9 and 10 the authors had given the units consumed instead of the revenue, as it would then have been possible to compare the relative consumptions. I agree that an assisted-wiring scheme is absolutely essential for securing load in rural areas. By "assisted wiring" I mean a scheme under which the installation is put in free of initial charge and paid for by an addition to the cost of the unit, collected through a slot meter. In the Wolverhampton area it was impossible to secure rural consumers until such a scheme was introduced, and in villages which have recently been developed 70 per cent of the consumers have adopted it. I do not think the authors' suggestion to include the cost of the wiring in the capital charges for the development scheme is good business, as it is found that people are exceptionally careful with anything which will eventually belong to themselves, and anyhow the additional capital charges would have to be recovered in the charges made for electricity. The authors recommend a distribution voltage of 11 000 volts: this requires modifying when the rural supply forms part of a 6 600-volt network, but the system should be laid out in such a way that it will be suitable for 11 000 volts when the load justifies the increase in voltage. If this is done, the very heavy losses of step-up transformers are eliminated in the early stage of development. With regard to the constructional details given in the paper, I am sorry to note the omission of an illustration of the wish-bone construction, with wires grouped in a tipped triangle, which in my opinion is the most satisfactory form. The actual iron work may be a little more expensive than that of some of the types illustrated, but, as only two pieces of iron and three bolts (two through the pole and one joining the iron members together) are required, the reduced cost of erection goes far to balance the initial cost of the arm. The lines illustrated make extensive use of angle iron: in my opinion channel section is to be preferred, as it affords a firmer support for the insulator pins. It is better to make the principal members sufficiently strong to avoid the necessity of stays and struts, and, as corrosion takes place from the surface, any design which reduces the exposed surface of the metalwork to a minimum is desirable. With regard to h.t. fuses, I prefer to use the pull-down type, even for the smallest loads, as it is very difficult to operate a pole on a wet and windy night. The type of l.t. line recommended by the authors is becoming general throughout the country, and it is extremely satisfactory. I find that in most villages it is necessary to bring the high-tension line into a kiosk in the centre of the village by means of underground cables, and then to radiate with short l.t. underground feeders through the crooked roads in the centre and to employ overhead distribution lines as soon as it is feasible. I have found this cheaper than carrying out the whole scheme by means of overhead lines, as it avoids the heavy expense of angle poles, stays, struts, etc. The authors' suggestion of putting poles at the back of houses is generally not feasible, for the reason that where there are houses on both sides of the road poles at the back of the premises would, of course, mean two lines where one would serve if fixed in the roadway. Fortunately, the objection to overhead distribution in villages is dying down. In one rural area which I developed, however, the local authority insisted upon steel poles being used because they were slightly smaller and were therefore considered to be less unsightly than wooden poles. Iron poles involve difficulty in earthing. An iron pole standing in gravel soil does not make a sufficiently good earth connection to carry away the leakage current from a fault without raising the potential of the ground in the region of the pole; this once led to the electrocution of two horses. Where steel poles are used it becomes necessary to run an earth wire connecting all the poles together, so as to reduce the resistance to earth to a minimum. The authors do not touch on the details of line erecting: we now have in course of construction some 40 or 50 miles of overhead lines where the poles have been erected by means of sheer legs and block and tackle. This has slightly reduced the cost of erection, but the great advantage is that the heavy labour of pushing the pole into a vertical position is eliminated and the work can therefore be carried out satisfactorily by labourers of normal or even of poor physique.

Mr. F. J. Elliott: I propose to confine my remarks to the position of the consumer, particularly the type who uses electricity for domestic purposes only. As regards tariffs, I am glad to see that the authors (page 205) advocate a tariff based on quantity only, as I am convinced that some such simple basis has been needed for a long time. After all, quantity is accepted as a basis of purchase for every commodity and it is understood by everyone. I am afraid the authors are too optimistic with regard to the anticipated consumption for domestic purposes. Experience shows that in this type of area some 60 per cent of the consumers obtained take advantage of assisted-wiring schemes and consume less than 100 units per annum for lighting purposes. The revenue, including hire-purchase of the installation, is about £2 10s. per annum (approximately 1s. per week). This is greatly in excess of the cost of oil and candles, and in my opinion is the maximum expenditure for electricity that this type of consumer can afford. It therefore follows that to obtain the consumption per consumer shown in Table 20 the remaining 40 per cent of domestic consumers will have to average a greater number of units than that shown, and generally speaking this can only be done by the installation of heating and cooking equipment. Even if it is assumed that the running cost for this purpose is not more than that of the existing methods of heating and cooking, the consumer will have to meet the capital cost of the installations and apparatus by cash payment, hire, or hire-purchase. In conclusion, I suggest that whilst the price per unit is an important factor, it is by no means the only deterrent to a larger use of electricity for domestic purposes; the cost of apparatus and installation is an equally serious one, and at present it is not receiving the attention it deserves.

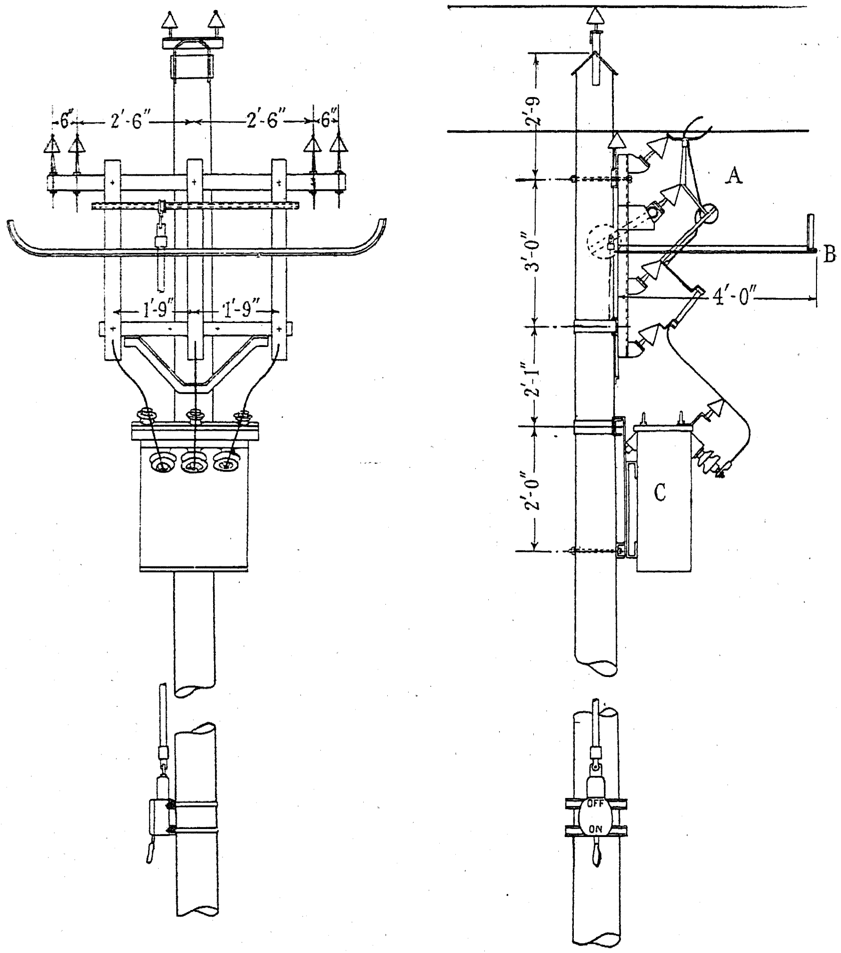
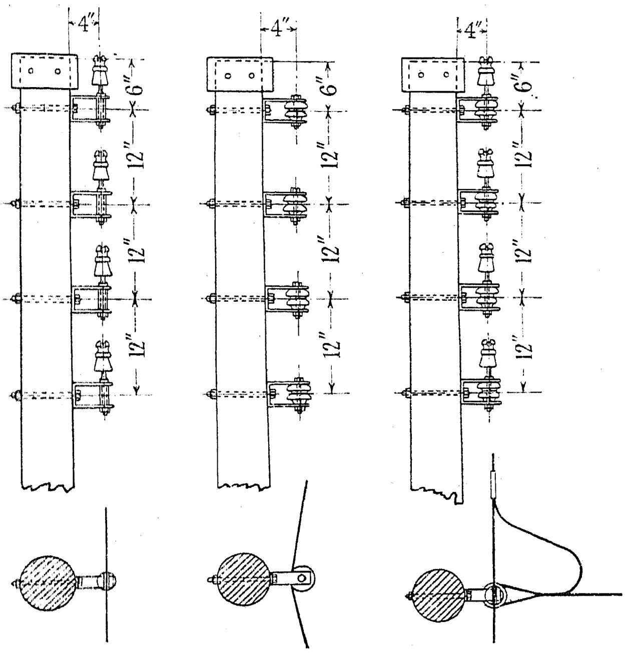


Fig. P.—Showing conversion of a straight-line road-crossing pole to a transformer pole.

Mr. H. S. Davidson: I propose to confine my remarks to one or two constructional features referred to in the paper. In connection with substations, the authors state that transformers up to 15 kVA can be erected on single poles and that for units from 15 to 50 kVA "H" poles should be used. It has been my experience that 3-phase transformers up to 25 kVA can conveniently be mounted on single poles. In order to facilitate the accommodation of the necessary switchgear on such poles and the conversion of existing single-line poles to transformer poles, I have developed a type of construction whereby the cross-arm carrying the two bottom conductors on a pole such as the authors recommend, is replaced by a slightly longer cross-arm, which, in addition to supporting the line conductors, forms the top cross-member of the switch and fuse unit. Such an arrangement is shown in Fig. P, and it will be seen that the result is extremely neat and provides the maximum ground clearance for the transformer terminals. It is simple to erect, and enables the conversion of an existing pole to be carried out with a minimum interruption of the supply on the overhead line. With regard to low-tension lines, I am in favour of the use of pin-type insulators on straight-line or small-angle positions. The conductor is laid in the top groove of a pin insulator, except at small-angle positions, and the weight of the conductor is not therefore on the binder as with shackle insulators when these are used on straight-line poles. The almost universal adoption of the " D " iron fitting has induced engineers to adopt shackle insulators throughout, but the " D " iron can be used with pin insulators by adopting the design shown in Fig. Q. In addition, at 3-way junction poles the shackle insulator supporting the tee-off line can be carried on the pin supporting the straight-through line. This results in a saving of pole fittings and obviates the use of any special type of construction for such positions. The connections between low-tension overhead lines and cable dividing-out boxes have been complicated by the fact that manufacturers continue to supply an inverted type of box, which, although eminently suitable for the older triangular-spaced lines, is almost useless for the vertical spacing now used so extensively. I am glad to see that at least one manufacturer is now supplying a type of box the outlets from which to the line are arranged in a vertical plane.



Straight-line pole. Small-angle pole and/or terminal pole. Straight-through 3-way junction pole.

FIG. Q.

Mr. A. Latham: With reference to switchgear, I am not satisfied that the arrangement of isolators shown in Fig. 25 for the protection of small pole transformers is warranted by the reduction in cost. More often than not supply failures occur in very bad weather or during the night, and my experience has been that the use of a long operating rod of 20 to 25 ft. is no easy matter, particularly in inclement weather. With regard to the pull-down type of switchgear illustrated in Fig. 26, these switches are usually mounted on single poles. Although the arrangement provided for bringing the fuses to ground-level for renewal is ideal, it has been found to have a disadvantage in that the switch unit cannot be mounted at a height of more than 20 ft. from ground; this necessitates long leads from the e.h.t. line in the case of 36-ft. line poles. Moreover, the transformer has to be mounted below the switch on the opposite side of the pole, which necessitates—in almost every case—running the l.t. overhead lines over the h.t. terminals. Outdoor transformers are almost invariably erected with bare terminals and bare leads, and it is therefore necessary to fix the l.t. fuses below the transformer on the same side as the switch, as in the case of single poles the other side has to be left clear for raising or lowering the transformer. This disadvantage is evident in any type of switchgear where the fuses are brought to the ground-level for operation. The substations shown in Figs. 27 and 28 with the kiosk or feeder pillar at the bottom of an " H " pole appear to be rather hybrid arrangements of rural and urban designs. I have had experience of transformers up to 125 kVA mounted on stout " H " poles. Dealing with the question of services to consumers, I should like to know whether the authors recommend the extensive use of 4-wire services for dealing with heating and cooking loads, as a multitude of 4-wire overhead services in a residential district can be very unsightly. Two-wire service lines can be erected more neatly if the service spans are taken direct from the line insulators, services from the back of the pole being connected to separate " D " irons fixed by the bolt holding the line " D " irons and insulators. The authors' estimated cost of house services at £2 each appears to be very low. In the " ribbon " type villages the houses and cottages are usually built a distance of about 15 to 20 yards from the road, necessitating long service spans, and if the meter is fixed in a pantry or scullery at the side or back of the house the length of " lead in " cable required is usually 15 to 20 ft. I suggest that the average cost of overhead services should be about £3 to £4 per house. With regard to Tables 27 and 28, I notice that the same number of consumers is connected during the first year and the second year, although considerably more consumers should be added in the second year. No allowance appears to be made for the fact that a few months would elapse in the first year before any supplies whatever could be made available, and at the end of the first year less than half the scheme would have been completed. Referring to Fig. 12, the authors base their estimate upon one transformer tapping per parish. A general review of the rural areas in Staffordshire, Shropshire, and Cheshire, shows that almost invariably there are at least two and sometimes three smaller villages or hamlets which can only be supplied from separate transformer tappings and l.t. distribution systems. The authors provide for four small-transformer tappings for isolated farms, etc., per parish of 4 square miles, but the hamlets referred to do not come under this category of " isolated " loads. I suggest that their estimate of 96 village equipments is too low, and that the length of l.t. lines per parish (Table 25), is also on the low side, although the actual length of l.t. distributors would appear to be too great to be supplied from a single transformer point.

Mr. W. E. Groves: During the last six years I have had to lay out the distribution system for a rural area of 100 square miles adjoining the Birmingham city boundary, and it is interesting to find how closely the authors' recommendations follow the scheme carried out in this area, although in this case the main source of supply is very far from the centre—in contrast with the authors' model diagrams. This confirms their statement that distortion will not materially affect design. As substantial interlinking of rings is apparently contemplated, I should like to know what system of protection is proposed that will prevent interruption of supplies on a large scale in the event of faults. For dealing with unbalance on l.t. distributors, very considerable benefit can be derived by installing interconnected star balancers on the pole nearest to the seat of the trouble. These balancers are small and easily transported from place to place as required. While it is not impossible to parallel distributors fed from adjoining transformers, certain precautions are, of course, necessary for safety. As regards e.h.t. pole types, I notice that the one shown in Fig. 21 is recommended in the conclusions, although Fig. 18 is preferred in the earlier part of the paper. It is, I think, preferable to use sloping cross-arms (which are inconvenient to birds) than to make a comfortable perch and then fix additional gear to render it uncomfortable. Channel-iron construction is to be preferred to angle-iron for attachment of insulator pins. The former also makes a more robust construction and is essential where long pins are employed. A fuse-link which has to be worked by a pole from the ground is shown in Fig. 25. Although this is the cheapest arrangement, it is very unsatisfactory for operating in darkness or bad weather, or both. The cost of ground-operated mechanism is out of all proportion to the cost of the small pole transformer, but it is sometimes possible—where small transformers for supply to farms, etc., are on a spur line—to provide one such fuse-link for controlling several transformers. This is a cheap and convenient compromise. Expenditure on kiosks is not justified in rural areas unless special conditions, such as appearance or security, render them necessary. Size has no bearing on this point. Modern practice is to place the largest transformers out of doors, and cheap and efficient outdoor oil-switches are obtainable. It would be interesting to know the authors' views on the question of supplying for farm use from individual transformers, a lower voltage than the standard. The relative risk to life attending the use of 220 volts as compared with 110 volts has been stated* to be 8 : 1.

Mr. C. W. Loveridge: As a contractor who has specialized in the construction of overhead lines, I should like to say something on the criticisms that have been made of the costs given for high-tension and low-tension lines. On a scheme of the magnitude outlined by the authors, generally speaking I should be happy to undertake the work at the prices stated. However, I think their figure of £2 for low-tension services is too low and that the prices given for substations, where first-class work is called for, do not allow a sufficient margin for transport and erection. It is not possible to generalize about the cost of lines and to quote a definite price per mile. Owing to wayleave delays or weather conditions it is quite possible that a line the construction of which presents no physical difficulties may cost more than a line over more difficult country. A smoothly working organization reduces delays to a minimum and brings down the cost of overhead lines. In my view one of the causes of the relatively high cost of some schemes has been the overlapping of various departments and interests. My firm has recently made an effort to "rationalize" the development of rural areas. On the Eccleshall ring in Staffordshire, which we have just completed for the North-West Midlands Joint Electricity Authority, and which consists of some 20 miles of high-tension lines and the substations and distribution systems in 10 villages, we as contractors under our own organization have secured wayleaves, constructed the lines, canvassed for consumers, and wired the houses. The whole of the work has proceeded simultaneously under one management, with a considerable saving of time and money. Before the constructional work had been completed we had obtained sufficient consumers to give a revenue which will, we hope, cover all charges on the work and perhaps leave a small balance. This has been accomplished in a very sparsely populated area. A previous speaker stated that the authors' figures for the percentage of the available number of consumers on the lines that could be connected up in the first year are too high. By our special methods we have been able to achieve more than double the percentage given by the authors, and had tariffs been more favourable we should no doubt have been even more successful.

Mr. J. A. Sumner: I should like to draw the authors' attention particularly to Table 25, in which the cost per mile of line for varying circumstances is set out. I would suggest that the term "Cost per mile" (a very ambiguous term) is particularly misleading in this case, as it implies that the whole of the line work, comprising supply, delivery to site, erection, as well as the accompanying overhead costs which include the total cost per mile, are embodied in the costs set out in the table. On referring to the "Statement of Expenditure" on pages 230 *et seq.* I note that the first item allocates the sum of £10 830 for wayleaves and survey, which is equivalent to a cost of £32 per mile, or alternatively 10 per cent additional to the total cost of h.t. lines; this, I suggest, should have been added to the figures in Table 25. On referring to Item 2, it is clearly seen that the cost per mile is for all material supplied and delivered and for erection, including two crossings per mile. Are these crossings Post Office crossings or normal road crossings with the usual protection? In general, my criticism is that Table 25 is liable to mislead the reader, and it is particularly important that a clear picture should be available, owing to the considerable future use which will undoubtedly be made of this paper for reference purposes. There is not the least doubt in my mind that the figures in Table 25 are sufficient to cover the cost of supply to site of materials, delivery and erection; in fact the authors would appear to have been fairly generous in their costing for these items. The results of a recent analysis of the costs of various methods of providing protection at Post Office crossings, for an 11 000-volt 3-phase line, may be of interest. The various costs for an average crossing were found to be as follows:—

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* A. Ekström and V. Ekström: "Rural Electrification," p. 12.

	£	s.	d.
(1) Cost per crossing when Post Office provide an underground cable (at undertaker's cost)	27	0	0
(2) Cost when undertaker erects guard (minimum specification)	39	15	0
(3) Cost when undertaker provides underground cable crossing	72	13	3

It will be seen how the total cost per mile of line can be increased if there are many crossings of type (3). In connection with the question of road crossings, I am pleased to note that the authors do not put forward the duplicate bound-conductor crossing as an alternative method. Have they any views as to its unsuitability? Referring to the various types of design reviewed in the paper, I should like to stress the overruling need to provide a design that is æsthetically satisfactory; my own view is that the type shown in Fig. 19 combines the æsthetic with a satisfactory practical design.

[The authors' reply to this discussion will be published in a later number of the *Journal*.]

Additional Written Communication to the Discussion before The Institution (see Page 235).

Captain J. G. Hines (*communicated*): I am impressed by the similarity in presentation between the present paper and that on "The Anticipation of Demand, and the Economic Selection, Provision and Lay-Out of Plant (Telephone Systems),"* read before the Institution in 1929. The present authors' treatment confirms the statement then made that there is much in common between power and telephone systems so far as the economic provision of plant is affected. In fact, much of what is stated in the text and indicated in diagrams by the present authors would apply to telephone systems if the names of the units were changed. It is a little disappointing to find that few of those taking part in the discussion have dealt with those portions of the paper in which the economics of plant provision are described, especially as this subject is so important and it appears to be the main purpose of the paper to deal with it. On page 206 the authors emphasize that "when designing a scheme, plant must be projected for the whole area and must be adequate for present and future needs . . . this is by far the cheapest way in the end, the old method of sporadic developments being open to many pitfalls." It is suggested that if an effective comparison is to be made between the ultimate costs of providing plant in small or large instalments, the method to be employed should be that of a comparison of the present value of the annual costs of possible alternative methods for the whole period under consideration. This method has been used for many years by the Post Office in planning telephone plant development. The authors would probably have been able to present their case in a still more convincing manner if they had used the same method. Several references are made to the fact that the load will grow, and the problem is to ascertain how much plant ought to be provided at one time to meet this growth. If plant is provided in small instalments the immediate capital expenditure is kept low, but the cost per unit will be relatively high. If very large instalments are provided the cost per unit may be much lower, but there will be an increase in the annual charges on idle plant. Between the extremes there is a period for which it is most economical to provide plant. If the present values of the annual costs for the various possible planning periods are plotted it will generally be found that the curve is almost flat at the bottom; that is to say, there is a period of a few years over which the planning period may be varied without appreciably affecting the present value of the annual costs for the whole period under consideration. If capital is cheap and the cost of labour and stores low at the time of investigation, it will be desirable to plan for as long a period as possible without incurring an appreciable increase in the present value of the total costs. By this method provision can be made at small cost for variations from the forecast growth. If, however, capital and other items are dear at the time of investigation and are likely to become cheaper subsequently, it is desirable to plan for the shortest period over which the curve is flat. Before making a decision as to the planning period to be adopted it is necessary to have (*a*) a graph showing the variation in present value with the variation of planning period, (*b*) the figures of immediate capital expenditure involved in the possible alternative methods, and (*c*) the best estimate that can be obtained of the future tendencies of interest, stores, and labour costs. If capital costs alone are considered, an erroneous conclusion may be reached. On page 191 the authors state that "the estimate of development should cover a period of, say, 6 years and should be based, as far as possible, on an actual canvass and on experience in other areas, etc." The Post Office considers that detailed examination of each area is essential. It makes an actual survey of every area in the country, and forecasts for 20 years ahead are made in periods of 5 years. These forecasts are reviewed every 5 years, and amended as necessary. If additional plant is to be installed the engineer in charge of the area has the forecasts of development available, and, moreover, is kept supplied by experts with data which enable him to provide for the most economical period based on the anticipated rate of growth and other relevant circumstances. In connection with Fig. 1 the authors state that an estimate which is based on an even distribution of load will be the highest. This is not necessarily so. If Fig. 1 had been drawn so as to have a cluster of consumers in each of the corners of the rectangle, and a very low density of population in the centre, it would have been found that the cost per line would have been higher than when the lines were evenly distributed. It frequently happens in telephone practice that none of the clusters is large enough to justify separate exchanges and it is better to serve the clusters from one point at the economic centre. Presumably such cases will also arise in power distribution. The method adopted by the authors of assuming regular distribution for the purpose of framing a model lay-out is justified, and it has been adopted by the Post Office for a similar purpose. The average cost of providing lines in such uniform areas of various sizes and densities is ascertained and the most economical size of exchange determined. When an irregular area is under consideration the average length of line is determined and the equivalent area of uniform density ascertained. Data which have been obtained for the uniform area can then be used as a guide in dealing with the irregular area. The necessity for many tedious special calculations is thus avoided. In the paragraph headed "Village Distribution Networks" on page 209, it is stated that the transformer station is assumed to be "in or near the centre of the village." In determining the economic position it is necessary to consider not only the distribution of the load in the village, but also the direction of the feed to the transformer. There will be an economic pull towards the direction of feed, and this must not be overlooked when calculating the minimum cost of distribution and searching for a suitable site. On page 222 it is stated that a Post Office pole is usually found installed in the best spot in the village. It is good to have this statement from such competent observers. This is where a telephone pole should be, but the local engineers have great difficulty at times in securing such positions and it was feared that opposition might have led in many cases to acceptance of something much less than the best.

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* J. G. Hines: *Journal I.E.E.*, 1929, vol. 67, p. 594.

[The authors' reply to this communication will be published in a later number of the *Journal*.]

ANNUAL DINNER, 1932.

The Annual Dinner of the Institution was held at the Connaught Rooms on Thursday, 4th February, 1932, when the President, Mr. J. M. Donaldson, M.C., presided over a gathering of nearly 700 persons. Among those present were: Mr. P. J. Pybus, C.B.E., M.P. (*Minister of Transport*); The Rt. Hon. The Viscount Falmouth (*Member of Council*); Mr. John W. Dulanty, C.B., C.B.E. (*High Commissioner for the Irish Free State*); Sir Frank E. Smith, K.C.B., C.B.E., D.Sc., LL.D., F.R.S. (*Secretary to the Council, Department of Scientific and Industrial Research; Secretary, Royal Society*); Sir Edward A. Gait, K.C.S.I., C.I.E. (*Chairman of Council, Royal Society of Arts*); Sir Murdoch MacDonald, K.C.M.G., C.B., M.P. (*Vice-President, Institution of Civil Engineers*); Sir Philip A. M. Nash, K.C.M.G., C.B.; Sir Gerald F. Talbot, K.C.V.O., C.M.G., O.B.E.; Sir William Bragg, O.M., K.B.E., F.R.S. (*Fullerian Professor of Chemistry, Royal Institution*); Sir Arnold B. Gridley, K.B.E.; Sir Cyril W. Hurcomb, K.B.E., C.B. (*Permanent Secretary, Ministry of Transport*); Sir Joseph E. Petavel, K.B.E., D.Sc., F.R.S. (*Director, National Physical Laboratory*); Sir Robert Robertson, K.B.E., D.Sc., LL.D., F.R.S. (*Government Chemist*); Sir J. R. Brooke, C.B. (*Vice-Chairman, Electricity Commission*); Sir Clement Hindley; Sir William Noble; Sir Archibald Page (*Past President*); Col. Sir Thomas F. Purves, O.B.E. (*Past President, I.E.E.; Engineer-in-Chief, General Post Office*); Sir William Slingo; Col. A. S. Angwin, D.S.O., M.C. (*Chairman, Wireless Section*); Mr. Ll. B. Atkinson (*Past President, I.E.E.; President, British Electrical Development Association*); Mr. H. R. Beasant (*Hon. Secretary, Western Centre*); Mr. John Brass (*Acting President, Institution of Mining Engineers*); Mr. R. A. Chattock (*Past President*); Lieut.-Col. E. Kitson Clark, T.D., M.A. (*President, Institution of Mechanical Engineers*); Mr. A. R. Cooper (*Member of Council*); Mr. M. H. Damme (*President, Koninklijk Instituut van Ingenieurs*); Dr. C. V. Drysdale, O.B.E., F.R.S.E. (*Director of Scientific Research, Admiralty*); Mr. R. N. Eaton (*Hon. Secretary, Irish Centre*); Mr. W. C. Eaton (*Principal Asst. Secretary, Technological Branch, Board of Education*); Dr. W. H. Eccles, F.R.S. (*Past President*); Dr. T. Watts Eden (*President, Royal Society of Medicine*); Lieut.-Col. K. Edgcumbe, T.D., R.E.T. (Ret.) (*Past President*); Mr. H. C. Fraser (*Hon. Secretary, North Midland Centre*); Mr. R. Grierson (*Member of Council*); Mr. W. Craig Henderson, K.C., D.Sc.; Lieut.-Col. A. P. Heneage, D.S.O., M.P. (*Parliamentary Private Secretary, Ministry of Transport*); Mr. J. S. Highfield (Past President); Mr. E. W. Hill (*Member of Council*); Mr. H. L. H. Hill, M.A., F.C.A. (*President, Institute of Chartered Accountants*); Mr. Frank Hodges (*Central Electricity Board*); Mr. P. M. Hogg (*Chairman, Mersey and North Wales Centre*); Mr. H. Hooper (*Hon. Secretary, South Midland Centre*); Mr. J. F. W. Hooper (*Member of Council*); Mr. J. M. Kennedy (*Vice-President*); Mr. J. E. Kingsbury; Mr. F. C. Knowles (*Chairman, Meter and Instrument Section*); Lieut.-Col. A. G. Lee, O.B.E., M.C. (*Member of Council*); Mr. E. Leete (*Hon. Treasurer*); Mr. S. C. Lewis (*Chairman, Association of Consulting Engineers*); Mr. A. L. Lunn (*Past Chairman, North-Western Centre*); Mr. R. K. Morcom, C.B.E., M.A. (*Vice-President*); Mr. W. M. Mordey (*Honorary Member* 1932; *Past President*); Prof. G. T. Morgan, O.B.E., D.Sc., F.R.S. (*President, Society of Chemical Industry*); Brig.-Gen. Magnus Mowat, C.B.E. (*Secretary, Institution of Mechanical Engineers*); Mr. C. G. Morley New (*President, Incorporated Municipal Electrical Association*); Lieut.-Col. H. E. O'Brien, D.S.O.

(*Chairman, Irish Centre*); Mr. Clifford C. Paterson, O.B.E. (*Past President*); Dr. S. L. Pearce, C.B.E.; Mr. Frank Pick (*President, Institute of Transport*); Mr. A. J. Pratt (*Past Chairman, Mersey and North Wales Centre*); Mr. F. W. Purse (*Vice-President*); Mr. H. A. Ratcliff (*Member of Council*); Dr. E. H. Rayner, M.A. (*Member of Council*); Mr. G. Rogers (*Past Chairman, South Midland Centre*); Mr. L. Romero (*Chairman, North-Western Centre*); Mr. N. B. Rosher, O.B.E. (*Chairman, South Midland Centre*); Dr. A. Russell, M.A., LL.D., F.R.S. (*Past President*); Mr. Ernest Sanger, J.P. (*Chairman, London County Council*); The Rev. E. St. George Schomberg, J.P. (*Mayor of Westminster*); Mr. E. E. Sharp (*Member of Council*); Mr. L. Simon, C.B. (*Director of Telegraphs and Telephones, General Post Office*); Mr. R. P. Sloan, C.B.E. (*Member of Council*); Mr. Roger T. Smith (*Past President*); Mr. C. P. Sparks, C.B.E. (*Past President*); Mr. L. Sylvester Sullivan (*Vice-President, Royal Institute of British Architects*); Mr. J. W. Thomas (*Hon. Secretary, North-Western Centre*); Mr. H. T. Tizard, C.B., F.R.S. (*Rector, Imperial College of Science and Technology*); Mr. J. W. J. Townley (*Member of Council*); Mr. J. Ulrich (*President, Société Française des Électriciens*); Mr. F. Wallis (*Chairman, British Electrical and Allied Industries Research Association*); Mr. R. G. Ward (*Chairman, North Midland Centre*); Mr. V. Watlington, M.B.E. (*Member of Council, I.E.E.; Chairman, British Electrical and Allied Manufacturers' Association*); Mr. O. C. Waygood (*Hon. Secretary, Mersey and North Wales Centre*); Major J. Wayne-Morgan, M.C. (*Chairman, Western Centre*); Mr. B. Welbourn (*Vice-President*); Mr. R. S. Whipple (*Member of Council*); Col. R. H. Willan, D.S.O., M.C. (*General Staff, War Office*); Mr. T. P. Wilmshurst, M.B.E. (*Electricity Commissioner*); Mr. M. F. G. Wilson (*Chairman, British Standards Institution*); Mr. W. B. Woodhouse (*Past President*); and Mr. P. F. Rowell (*Secretary*).

The toasts of "His Majesty the King" and "Her Majesty the Queen, His Royal Highness the Prince of Wales, and the other members of the Royal Family," were proposed by the President and were loyally received.

The President read the following messages from kindred Institutions abroad:—

From the Italian Electrotechnical Association.

"Best wishes for your Institution. Bordoni, President, Associazione Elettrotecnica Italiana."

From the Belgian Society of Electricians.

"The members of the Société Belge des Électriciens desire to be remembered to their British colleagues and send to their Association every best wish for its prosperity."

Mr. P. J. Pybus, C.B.E., M.P., (Minister of Transport) in proposing the toast of "The Institution," said: "The pleasure with which I rise to propose this toast is increased by the fact that among the members are the friends and colleagues of a lifetime, and that the Institution itself is a governing body in the industry in which I have spent most of my working life. It must be intensely gratifying to all those connected with the industry to know that Britain alone of the great industrial countries of the world showed an increase in 1931 in the output of electricity by public supply undertakings. We are apt to regard 5 per cent as a very small matter, but those who are connected with electricity supply will rejoice with me when I say that an increase of no less than 4·5 per cent was registered last year. Since 1927 Great Britain has done a great deal to remove the reproach that in electrical development she was backward as compared with the rest of the world. For the five years 1927 to 1931 the expansion in the output of electricity from public supply undertakings was 35 per cent for Great Britain, 15·3 per cent for the United States, and 18·5 per cent for Germany, and I am glad to know that, at any rate so far as electricity is concerned, this country has escaped some of the worst consequences of the world crisis. I have been a little surprised, however, to note the complacency with which the electrical industry apparently views the transfer of an enormous electrical road-traction load to the impulse engine. The movement for the scrapping of tramways and their replacement by the impulse engine has, possibly, gone too far and too fast; but, if a change-over is to be made, I should like to refer to the possibilities of the electric trolley vehicle. The perfection of that vehicle and its adoption in suitable cases would, I feel, go a long way towards helping some home industries, and in particular the coal-mining industry; and I hope that the supply undertakings will do what they can by offering the current at a very low price in order to save this traction load for the electrical industry. Not only Ministers of Transport but those in charge of all the technical Ministries have long recognized the generous help which the Institution has so long and so freely given to the State. Referring to the Central Electricity Board, I should like to mention a few particulars which show the progress of the grid in 1931. The actual construction has now reached 2 310 miles, of which 1 500 miles were added during the year. The 1 600 miles still to be completed will, it is hoped, be finished in the early spring of 1933. One of our troubles is to secure all the wayleaves over the countryside for the pylons and the overhead cables. The total wayleaves secured in 1931 amounted to 1 700 miles, leaving only 500 miles to be obtained; and I am glad to be assured by the Central Electricity Board that a satisfactory feature of, at any rate, this side of the work is the happy co-operation of the landowners, the farmers, and all those people who are anxious to preserve the amenities of the countryside. As an instance of this co-operation, out of 10 000 consents only 233 required a delicate touch of compulsion. I should also like to mention a few figures showing the enormous volume of contracts placed with the electrical industry as a result of the development of the grid. Inclusive of the standardization of frequency, no less a sum than £30 000 000 has been allocated to contracts for the development of our industry. The Board have expedited certain sections of the grid, with the result that it has been possible to save £2 250 000 worth of generating plant. Much remains, however, to be done before the consumer feels the effect of this centralization of electricity supply throughout the country, and I hope that our next work will be some step towards increasing the distribution at low voltage. In conclusion, I cannot sit down without referring to what has taken place to-day in the House of Commons. In a crowded House all eyes were turned on the Chancellor of the Exchequer as he rose in his place, but to most of us there was an overwhelming feeling of the presence of a great statesman long since gone from our midst. We felt that the pages of history were being rolled back a generation; for 28 years ago, almost to the day, Mr. Joseph Chamberlain sacrificed his seat in the Cabinet and went into the political wilderness for his ideals and convictions. In the actual seat in the House to which he retired after taking that step there sat to-day his son, Sir Austen Chamberlain, so strangely like his father as to give the scene an amazing sense of drama."

The President, in responding to the toast said: "We are pleased to have this toast, the principal one of the evening, proposed by a member of the Institution. Although it is rather hackneyed to speak of electricity being in its infancy, I propose to do so. I do not, however, intend to deal with the history of electrical engineering. All I wish to say is this: that we cannot be very old, because only last year we celebrated the centenary of Faraday's great discovery, which marked the beginning of electrical engineering as we know it, and for half the following century very little was done; and then, when we electrical engineers did form an Institution, it was not termed 'of Electrical Engineers' but 'of Telegraph Engineers.' That was only 40 years ago, so we are really not very old. Instead of referring to our history, I will say a word or two about our ancestry. It seems to me that civil engineers were the founders of civilization as we know it, for if there were no roads and bridges and communications between different communities the interchange of ideas and of commodities would be impossible. Civil engineers must therefore take a very high position in the building up of the modern world. It seems to me that the Romans recognized this, because I remember that the high priest of the Roman hierarchy was called Pontifex Maximus, which means, I take it, the chief bridge-builder. I have always had a great love for the Romans, and we in this country owe a great deal to them. We sometimes look upon ourselves, the British race, as Anglo-Saxons with a sub-structure of the Celt and a little touch of the Norman later, and we are apt to overlook altogether those very fruitful three or four centuries when the Romans ruled in this land, not as taskmasters but in the curious colonizing way which we British have learned from them. I myself think that we have a great affinity with the old Romans. Our desire to do everything in order, to have our roads straight and tidy, our bridges good, our population well looked after and responsible citizens, comes from them. Baths, of course, the Romans were very fond of, and they had as a result of their tidy minds an inveterate habit of making laws, which we certainly have inherited. The Romans, as I say, left their mark on this country, but there was a long interregnum when things were by no means good, when the roads were neglected, and when travel and commerce failed to a large extent. Then we came to the era of the stage coach, and civil engineers came into their own again and began to build up that wonderful road system which I think is a model for the world to-day, although it is a very curious thing that some of the things which were done a hundred or two hundred years ago are regarded by many as the work of the Romans, when they are nothing of the kind, i.e. the 'arterial roads' of the later coaching period. However, the stage coach had its day, and then we came to the era of steam, which was the next great advance; and then mechanical engineers came into their own. Then we had that very fine combination of the civil and mechanical engineer known as the railway engineer, and the railway engineers built up a system of railways which is the best in existence at this time; and our grief as engineers is this, that it looks as if the railways were in for a worse time than they are having even at present. Nothing could be more dreadful to us as engineers than to think that our wonderful system of railways should degenerate into ineffectiveness like the canals of this country. I venture to think, however, that the electrical mouse may perchance be the means of gnawing through the cords which bind the railway lion. We all know that the conditions in this country are not precisely the same as those in other countries, and that experience abroad must be modified by reference to our own conditions. Considerable experience is available of electrical railway operation on a large scale in other countries, and I believe that conditions here are more favourable than they are in those countries. I suggest, therefore, that an enterprising railway manager should make a full-scale experiment on a length (it need not be more than 200 miles) of main-line railway. It must be main line, and it must have mineral traffic as well as passenger traffic. Having done that, railwaymen will be able to satisfy themselves as to the truth of certain things which they have always been told. There is first the great advantage of superior flexibility, and all that arises therefrom. Secondly, the saving of labour. Thirdly—and this is a very important point—the saving in maintenance costs, and the shorter time, therefore, for which the capital (namely the outlay on the tractors) is lying idle. All the other details are so well known that they do not need to be worked out again; but let this experiment be boldly tried and the results will flow from it. We for our part will be only too pleased to assist our brethren on the civil and mechanical sides to accomplish this great work. Coming back to the subject of our infancy or youth, if we are accused of being extraordinarily young, let us at least hold fast, as I think we do, to the youthful virtues of courage and enthusiasm, and also, I hope, modesty, and let us make up our minds that in the next quinquennium we shall double the output of electricity and at a considerably reduced cost. Let us try to install 10 telephones where there was one before, and install 100 wireless sets where one was made and installed before, and make progress along all the other lines in which we are engaged. Let us go forward, therefore, with courage, having always for our motto 'Electricity in the Service of Man.'"

Lieut.-Col. K. Edgcumbe, T.D., R.E.T. (Ret.), (Past President) then proposed the toast of "Our Guests," to which **Mr. J. Ulrich** (President of the Société Française des Électriciens), **Mr. M. H. Damme** (President, Koninklijk Instituut van Ingenieurs), and **Mr. H. T. Tizard, C.B.E., F.R.S.,** (Rector of the Imperial College of Science and Technology) responded.

A reunion was subsequently held.

INSTITUTION NOTES.

Unauthorized Use of the Initials "A.M.I.E.E."

On Friday, 19th February, 1932, in the Chancery Division of the High Court of Justice, Counsel on behalf of the Institution applied to commit to prison, Thomas Ronald Shaw, carrying on business as Cestrian Electrical Co., of Northgate, Chester, for breach of a perpetual injunction restraining him from using the initials "A.M.I.E.E." after his name.

Mr. Shaw appeared in person in answer to the Motion. Evidence was before the Court that the Defendant was not qualified to use the initials and the use of the initials was calculated to deceive the trade and the public and was liable to bring discredit on the members of the Institution; that while carrying on business in Wrexham in 1926 he was found to be using the letters in question and the Institution had required him to cease doing so; that he had replied that his action was due to a misunderstanding and he would refrain from using the initials in any way; that in 1928 he was found to be using the initials again, and that in an action brought against him a perpetual injunction was granted by the High Court of Justice restraining him from using the initials referred to or any other initials calculated to lead to the belief that he was a member of or connected with the Institution. The evidence further showed that on the 26th January of this year Shaw was again using the initials "A.M.I.E.E." The Institution therefore applied by Motion for a committal Order.

Shaw apologized to the Court and to the Institution and craved the mercy of the Court. His explanation was that some old letter paper had been used by mistake but that he had now destroyed the remaining sheets of the paper.

His Lordship, Mr. Justice Eve, agreed with the submission made by the Institution's Counsel that it was quite clearly a case of a flagrant breach of the order of the Court, but as Shaw had apologized to the Court he would not be sent to prison on this occasion. His Lordship cautioned him not again to commit a breach of the injunction and ordered him to pay the costs of the proceedings.

Proceedings of the Meter and Instrument Section.

22ND MEETING OF THE METER AND INSTRUMENT SECTION, 6TH NOVEMBER, 1931.

Mr. J. M. Donaldson, M.C., President, took the chair at 7 p.m.

The minutes of the meeting held on the 1st May, 1931, were taken as read and were confirmed and signed.

A vote of thanks to Mr. E. Fawssett for his services as Chairman during the session 1930–31, proposed by Mr. W. Lawson and seconded by Mr. R. S. J. Spilsbury, was carried with acclamation.

The President then vacated the chair, which was taken by Mr. F. C. Knowles, Chairman of the Section, who delivered his Inaugural Address (see page 36).

A vote of thanks to Mr. Knowles for his Address, proposed by the President and seconded by Mr. E. E. Sharp, was carried with acclamation.

The Chairman reported the award of Premiums for 1930–31 for Meter and Instrument Section papers (see vol. 69, p, 803).

The meeting terminated at 8.35 p.m.

23RD MEETING OF THE METER AND INSTRUMENT SECTION, 4TH DECEMBER, 1931.

Mr. F. C. Knowles, Chairman of the Section, took the chair at 7 p.m.

The minutes of the meeting held on the 6th November, 1931, were taken as read and were confirmed and signed.

A paper by Mr. V. Stott, B.A., entitled "An Investigation of Problems relating to the Use of Pivots and Jewels in Instruments and Meters" (see vol. 69, p. 751), was read and discussed (see vol. 70, p. 354).

The meeting terminated at 9.42 p.m. with a vote of thanks to the author, which was moved by the Chairman and carried with acclamation.

Elections and Transfers of Members.

At the Ordinary Meeting held on the 25th January, 1932, the following elections and transfers were effected:—

ELECTIONS.

Member.

Behrend, Bernard Arthur.

Associate Members.

Aisenstein, Simon.
Anderson, John Brunskill.
Brown, Stuart, Lieut.-Comdr., R.N.
Callow, Sidney Harrison.
Carter, Eric Thomas G., Major R.E.
Charley, Reginald Morse, B.Sc.
Christie, Charles Alexander, B.Sc.
Cowan, James Cecil A.
Cox, Harold John.
Davies, Evan Thomas.
de Alwis, Dionysius Richard C.
Derrington, John George F.
Evans, John, M.Eng.
Freeling, Francis Frederick.
Garton, Charles George.
Grey, John Bertram.
Higgs, Percival John, B.Sc.(Eng.).
Johnson, Richard Balderstone, B.Sc.
McCleery, David Kirk, B.Sc.
Macnaughton, Arnold Ingram, B.Sc.
McQuillen, William Thomson, Captain, M.Sc., M.A.
Mossay, Paul Alphonse H.
Newman, Jack Bolton, Lieut.-Comdr., R.N.
Pirie, Henry Arthur.
Quance, Frank Gordon.
Race, Allan Byers.
Ramsay, Cecil Graham.
Ramsey, Reginald Mitchell.
Rees, Augustus.
Saunders, Cyril Frederick S.
Speller, Alfred Gardner, B.Eng.
Stockwell, Robert Rae.
Stratten, Thomas Price, B.A.
Sutcliffe, Roland Arthur H., B.Sc.
Tchetchik, Zouche Alexander.
Warrior, Nates Krishna, B.Sc.

Companions.

Hudson, Ernest Walter.
Newton, Sir Douglas, K.B.E., M.P.
Read, Alfred Leonard.
Roger, Sir Alexander.

Associates.

Atkinson, Leonard Stewart.
Barrows, Edmund John.
Bennett, Cyril John G.
Burrows, James.
Chaplin, John Vivian.
Clark, Frederick Charles W.
Couse, Frederick Arthur.
Daniels, George McKenzie.
Davies, David Pendril.
Fuller, Edward Charles.
Furlonge, Lionel Stanley.
Habberjam, James.
Hall, William.
Heesem, Joseph Martin.
Kennedy, Alan.
Lipman, Isaac.
Lloyd, John Ladd.
Milner, Samuel.
Prichard, Edgar James.
Pywell, Ernest Arthur.
Read, Francis Edward.
Seaward, Thomas Stephen G.
Thomasson, Frederick, Flight-Lieut., R.A.F., D.F.C., M.M.
Walker, Harold Stephen.

Graduates.

Algar, Herbert William.
Alker, John.
Batho, Ernest William.
Bayley, John Magnier.
Bedekar, Gopal Vaman, B.Sc.
Bennett, Reginald S.
Bines, Arthur Thomas.
Blackburne-Maze, Leonard Norman.
Blackwell, Eric Althans.
Bowring, Frederick Alfred.
Calverley, Dudley Lewis W.
Cannon, Alan Hugh.
Carter, Edward Albert.
Chatterjea, Hari Prasad, B.Sc.
Cordingley, Stancliffe.
Datta, Promod Behari.
Denis-Marklew, Oscar Geoffrey.
Dewsnup, Roger Ritson, B.Eng.
Dix, Robert Raymond.
Dorkins-Kirschner, Ernest Frederick.
Eade, Stanley Robert.
Farkasch, Gordon.
Foale, Cecil William.
Gallop, John Winston.
Graham, Bertram.
Grierson, Robert.
Gullan, Archibald Gordon, B.Sc.(Eng.).
Harnden, Arthur Baker.
Harris, Leonard Michael, B.Sc.
Hogben, Roland Stanley.
Hopewell, Cecil John.
Kelly, William Swan, B.Sc.
Kenward, Fred.
Kinross, Rupert.
Lawrenson, Ernest.
Lees, Joe Henry.
Lindsey, Gilbert Thomas.
Lodge, Edwin Faville.
Lowe, Sidney Roland.
Merdler, Lionel Reginald.
Meredith, Albert Edwin.
Metson, Gilbert Harold, B.Sc.(Eng.).
Mitchell, James William E.
Mitra, Sanat Kumar, B.Sc.
Morris, William Ivor, B.A.
Myers, George Williams.
Neal, John Stewart, B.A.
Noble, Gerard William, B.E.
Ohn, Ma ung Tun, B.Sc.
Owens, Matthew Owen.
Padgett, Albert Edward.
Paterson, Alexander.
Pearce, Mark Swayne, B.Sc.Tech.
Pentland, The Rt. Hon. The Lord, B.A.
Pittendrigh, Lenus Walter D.
Porter, John Ernest.
Ralphs, Herbert Ronald P., B.Sc.
Reece, John Thomas.
Roake, William Henry.
Robinson, Geoffrey Seafield, B.A.
Rose, Frederic Campbell.
Salter, Stanley.
Shaw, Stephen.
Smith, Glen Nuttall, B.Sc.
Sprague, William Steains, B.Sc.

Graduates—continued.

Stimson, William Harold.
Straughen, Charles Robert G.
Surfleet, Walter Alan.
Teal, Arthur Edward.
Town, Irvine.
Tucker, Henry Valon.
Tudor, William Cowing, B.Sc.
Vaughan, Montague.
Virgo, William Richard S.
Wake, George Thomas.
Walker, Thomas Henry, B.Eng.
Wilkins, Harry Martin.
Williams, Norman Leslie.
Winder, Albert Edward.
Wolstenholme, Harry Doust, B.Sc., B.E.
Wong, Patrick Joseph, B.E.
Worthing, Robert Greenhill.
Zubiaga, Jose, B.Sc.

Students.

Acharya, Garud.
Ainley, Frank Edwin.
Ainsworth, Geoffrey Nichols, B.Sc.Tech.
Alder, Gordon.
Allardice, David Rutherford.
Allworth, Leonard.
Anthony, Donald Walter.
Appleton, John Swinburne.
Arumugam, Dindigal Arunachalam.
Arundell, Edward Periam.
Atchley, Kenneth Wilmot.
Atkinson, Leonard Henry.
Bailey, Joseph Charles.
Baines, Joseph Charles S.
Balchin, Douglas Bernard.
Baldwin, Ronald Haden.
Barnett, Ralph Ladislas.
Barwick, Emerson Clarke.
Basu, Deba Prasad, B.Sc.
Bater, Leslie.
Bawtree, Kenneth Scott.
Bean, Stanley.
Beatson, Cedric James.
Beatson, Elwyn Vivian.
Bebianno, Vasco.
Bennett, Charles Chapman.
Benson, Leslie Briggs.
Benstead, James William.
Bent, Charles Reichel.
Berrisford, Eric James.
Bhatt, Rasiklal Revashanker.
Biggar, Henry Peter H.
Billington, Reginald Moreton.
Bishop, Brian Walter S.
Bowness, Gill Brown.
Bowser, George Herbert.
Bowyer, Frederick Paget.
Bowyer, Leonard Frank.
Boyce, Thomas Richard.
Bradley, Reuben Stephen.
Brammer, George William G.
Bray, Philip Robert.
Bray, William John.
Brecknock, Howard.
Bristow, Kenneth Walter.
Brooks, Robert Hedley.
Buckley, Cornelius.
Bunce, Leonard Cecil.
Bunyan, Thomas Walter.
Burnett, Edward Frank.
Burrell, Maurice Barnard F.
Burton, Hubert George.
Butler, William Edward.
Cambatta, Sorab Nowroji.
Cameron, Donald Henry.
Campbell, William Fraser.
Cannon, Frank Herbert.
Carpenter, Alan Bertram.
Cator, Frederick Lumley.
Challans, Benjamin William S.
Chandler, Henry Charles.
Chant, Eric Roy P.
Chapman, Arthur.
Chapter, Colin Falconer.
Chen, Tai Kwei.
Chick, Percy Gaymer.
Clark, David Alexander S.
Clements, Dario Eugene.
Connock, Sidney Henry G.
Cowser, Harold.
Cresswell, Peter Charles.
Crouch, Frederick James.
Crowther, Charles Walker.
Dallimore, Joseph George.
Davies, Kenneth.
Deering, John Edward.
Derham, Thomas Reginald K.
Desmarais, Roland.
Deva, Yash Paul.
Dickens, Thomas Arthur J.
Dickinson, Frederick Harold.
Douglas, Gavin John G.
D'Sa, John George L., B.E.
Duraiswami, Thozur Madabusi.

Students—continued.

Ellis, Horace Dudley, B.A.
Elstob, Hedley Graham.
Emeny, Thomas Francis.
Everitt, Gilbert Norman.
Ewing, Edward Gregory.
Ferguson, John Robert.
Ferranti, Denis Ziani de.
Fielder, Ernest George A.
Finch, Charles Francis.
Flegg, Harold Leslie.
Fletcher, Ralph Owen.
Foster, Eric Hugh.
Frankton, Eric Victor.
Frith, John Edwin.
Gallop, Arthur Hubert.
Gardner, Stanley Douglas.
Garry, George Arnold.
Gerry, Cyril Harry.
Gesundheit, Julius Charles.
Ghose, Suresh Chandra.
Gibbs, David Francis.
Gibbs, Harold Ernest H.
Gilbert, George Douglas.
Gilbert, Humphrey George.
Gillham, Edwin Robert.
Gladwin, Francis Leighton.
Glover, Roy Phillips.
Godden, Alec William.
Godfrey, Robert Leonard.
Goldthorpe, Frank.
Gorman, Mervyn Edwin.
Green, Roland Guy.
Griffin, Wilfrid Roy.
Grobler, Pieter Schalk.
Groom, Sidney Herbert J.
Hamnett, Leslie George.
Harden, James George L.
Harman, Rowland.
Harries, George Gerald.
Harries, Roderick.
Harris, Albert William.
Hart, David.
Hayman, Trevelny Albert M.
Heal, Basil John L.
Henley, John Allan.
Henzell, Maurice Peregrine.
Hibell, Arthur Richard.
Hill, Kenneth.
Hirst, George Harry.
Hoare, Donald.
Holt, John Ogburn.
Holt, Peter.
Hooper, Ronald Studdy.
Hotham, Ernest Hector.
House, Leslie Edward.
Howell, Carrington John.
Hubbard, Carlos Douglas.
Hughes, David Islwyn.
Hughes, Vincent Alfred.
Hyland, Leslie.
Ireland, George Harvey C.
Isaacs, Bernard Reginald S.
Jones, John Nelson.
Kay, Harold Wilson.
Khan, Framjee.
Kinloch, Roger Peregrine.
Kinsella, William Bernard.
Koshary, Mahmoud A. B. El.
Koshairy, Mohammed A. B. El.
Krishana, Ganda Ram.
Lake, George James.
Lawrence, Harold Herbert.
Le Fevre, Edwin John.
Lennox, Robert.
Lobo, Camil Antony J. F.
Logan, Thomas Bastin.
Lunt, Charles.
Maclaire, Ian Carus.
Macdonald, Norman Somerled A.
McDonald, Fergus Gilbert.
McLachlan, James Romans.
McQuen, Archbold Henry.
Makinon, John Owen.
Manndiar, C. Vasudevan Uni.
Marsh Stephen Ernest.
Marti, Ernest James.
Martn, Harold Lewis.
Mauce, Richard Boyle.
Maxwell, Conway.
Merdith, Richard Sunderland S.
Meer, Edward William I.
Milr, Geoffrey Stuart.
Miler, Arnold Keith M.
Mihell, Roland Graeme.
Mioff, Basil.
Mry, Wadie.
Mson, Arthur Philip.
Mzoni, Mario Prestes.
Mley, William.
Mrrell, Alan Percy C.
Mrthy, Tiruvadi Venkaraman.
Nll, Ian Reid.
Nble, George Saint.
Ndder, Wilfrid George T.
OFlanagan, Michael Ryan.
OHara, Kean William.
borne, Stanley Frank.
swald, Thomas Dobson.
utram, Lionel John.
xley, Ronald.
alethorpe, Wilfred.
arkin, George Edward.
ask, Albert.

Students—continued.

Patterson, John.
Payne, Thomas Carruthers.
Pearce, Charles Arthur Richard.
Perrin, Maurice Raymond.
Pettitt, Harold Ernest.
Pillans, Gerald Scarth.
Pletts, John William.
Pocock, Sidney Frederick H.
Pollard, Leslie Charles.
Pope, Noel Baddow.
Postill, Charles Campleman.
Poulton, George William.
Pressey, Brian George.
Prichard, Richard Evan.
Prime, Alan Sydney.
Prout, Leslie Ronald.
Pycroft, Paul de Ferranti C.
Rappa, William.
Ratcliffe, James Corlett.
Rau, Bantwal Gopalakrishna.
Ray, Binoy Bhusan, B.Sc.
Ray, Jogat Bonduh, B.Sc.
Record, Francis Joseph.
Revell, Hedley James.
Robinson, Thomas Andrew
Robson, Francis.
Roden, Frank Albert, B.Sc.(Eng.).
Rogers, Joseph William.
Roper, Robert Francis.
Rudd, Charles George.
Russell, Archibald James.
Ruston, John.
Ryan, William Hope.
Salt, William Harvey.
Samson, George Gavin.
Sancto, William.
Sandys, Geoffrey Erskine.
Sawhney, Banarsidas, B.E.
Scoles, Graham John.
Scott, Colonel Conroy.
Scott-Maxwell, Ian Stephen.
Seymour, Philip Roy.
Sharples, John.
Shenoy, Gopala Krishna.
Shields, Ronald Frederick.
Shilling, Beatrice (Miss).
Shuhaibar, Shafic H.
Simpson, Christopher.
Sims, John Oliver.
Skenfield, William Malcolm.
Slaffer, Marks, B.Sc.
Slater, John Kendall.
Slingsby, Stanley.
Smith, Frederic Charles E.
Smith, Maurice Joy.
Smith, Raymond Leslie.
Smuts, William Beck.
Somasuntharam, George Devadason, B.Sc.
Somerville, Robert Dennis.
Stannard, George.
Stocker, Kenneth.
Subramanyam, Malasamudram Ramayya.
Sumner, John.
Sumner, Stephen Bailes.
Swift, George Philip.
Swinburne, Charles John.
Tabor, I.
Tapson, Ernest Lionel.
Tavener, Stewart Eric.
Taylor, Michael Rex P.
Taylor, Percy Heatley.
Thompson, John Oliver.
Thornton, Frederick.
Towers, Richard Walter.
Trolan, John.
Trotter, Ronald.
Trout, Norman Ridgill.
Ungoed, William Powell C.
Vardy, Jonah, B.Sc.
Varma-Raja, Mavelikara Valiakottaram R., B.A.
Viswanathan, Chinnaswamy Rajam.
Walker, Alec Hervey B.
Walkland, Harold Douglas.
Wallace, Sinclair Banks.
Walters, Henry Robert.
Walton, James William W.
Webb, James Beresford.
Webb, William.
Webber, Alexander.
Wheeler, Alan.
White, Cyril Herbert V.
White, George Edward B.
Whiteford, John.
Wickenden, Robert Henry.
Widdowson, William Frederick.
Wight, Robert Burton.
Williams, Charles Leonard T.
Williams, Duncan.
Williams, Eric George.
Williams, Frederic Calland.
Williams, Kenneth.
Williams, Robert James.
Wilson, Cecil Alfred.
Wood, Leslie Bertram.
Wood, Philip Morley.
Zammit, Emanuel.
Zoller, Ronald Ernest.

TRANSFERS.

Associate Member to Member.

Ashmore, Joseph.
Bose, Surendra Nath, M.E.
Brown, James Fowler.
Cheetham, George Arthur.
Dunlop, Robert Paterson, B.Sc.
Ewer, George Guy, Lieut.-Col., D.S.O., T.D.
Holttum, Worsley, B.Eng.
Jeffery, Leslie Brownlow G., B.Sc.
Knowles, Frank Clements.
Livesay, Arthur Cecil.
Mack, Robert Alfred, B.Sc.(Eng.)
Sharpley, F es Wilmot, Prof., F .E.
Sutcliffe, iam.

Associate to Associate Member.

Bleasdale, John William.
Bruce, James Malcolm.
Cockerill, Henry Walter.
Crymble, Clarence Frederick.
Lees, John Brearley.
Morton, Sydney Herbert C.
Smith, Hubert Alfred.

Graduate to Associate Member.

Arnold, Morris Hadrian.
Azimuddin, Mohamed, B.Sc.
Barnard, Howard Lucas, B.E.
Baxter, Henry Wright, B.Sc.(Eng.).
Bennett, Clayton.
Bishop, Geoffrey, B.Sc.
Bland, John George.
Boydell, Norman.
Brewin, James Edwin.
Bush, Alfred John.
Campbell, Ian Drummond, B.Sc.(Eng.).
Christie, John.
Clark, Reginald Erskine.
Clements, Vernon Arthur H.
Couzens, Dennis Frederick, B.Sc.
Cunha, Manuel Raul de F.
Daker, Horace Herbert, B.Sc.
D'Cruz, Cyril.
Douglas, Thomas Kenneth A., B.Sc.
Drury, George John S.
Dunkley, William Henry, B.Sc.(Eng.).
Dunlop, Maximilian.
Fernando, Edmund Clement, B.Sc.(Eng.).
Foden, George Emil G., B.Sc.
Forgan, Albert George, B.Sc.(Eng.).
Gower, Sidney Clayton.
Guthrie, Herbert James.
Hamlyn, Arthur Macfarlane.
Harrabin, Frank, M.Sc.
Helm, Leslie Robert D., Lieut.-Comdr., R.N. (Ret.).
Hoar, Harold George.
Hughes, Alexander Russell M., B.Sc.
Hughes, William Howard.
Ingham, Frank.
Illingworth, Joseph Priestley.
Jehu, John William, B.Sc.Tech.
Kilshaw, John Booth.
Long, Thomas Alban.
MacGregor, Roderick Marcus, M.Eng.
Mortlock, Joseph Ronald, B.Sc.(Eng.).
Nicholson, Hugh John G., B.E.
Parsons, David Cyril A.
Pearce, Arthur George.
Pearson, Eric John B., B.Eng.
Pegg, Arthur Crosskill.
Peters, Frank Martin.
Read, Frederick William.
Robertson, Eric Stanley.
Schou, Gaston Recardo.
Scott, Edward Chalmers, B.Sc.
Simpson, Norman George.
Smith, Roderick Alan.
Stretch, William, Jun.
Taylor, Henry George, M.Sc.(Eng.).
Taylor, John.
Thomas, Cyril Marsingall.
Thomas, Edward Arthur.
Voit, Reginald Austin.
Walker, William Gordon.
Ward, Frank Rogers.
Watson, Robert Parker, B.A.
Watts, John Lea.
Wells, John Spencer.
Wills, William Henry.

Student to Associate Member.

Axe, Leonard George, B.Sc.
Bagnall, Edward Alderson H.
Barratt, Noel Marshall, B.Sc.Tech.
Cawte, Charles William, B.Sc.(Eng.).
Cleveland, Harold Arthur.
Clibbon, Harold Alfred.
Collings, Henry Bernard.
Gates, Benjamin George, B.Sc.(Eng.).
Gubbins, John Bryan M.
Hardwick, John Rosewick, M.A.
Hastie, John Stewart, B.Sc.(Eng.).
Holmes, John Hardy, B.Sc.(Eng.).
Hunt, Douglas Hawthorn.
Kinsman, Albert Reginald, B.Sc.
Marshall, Frederick Geoffrey.
Milliken-Smith, Herbert.
Osborn, Leroy Gordon.
Percival, William Spencer, B.Sc.
Reed, Morris, M.Sc.(Eng.).
Reeves, Richard William C.
Robertson, Bertram Howard, B.Sc.
Summers, Frank.
Thomsett, Hector Stuart.
Tunnicliff, Eustace, M.Sc.
Walker, Gordon Mabor.
Watt, David, B.Sc.
Watton, Eric Bernard.

Student to Associate.

Graham, Douglas Ernest.
Mackay, Victor Peterson.
Mills, Arthur Kymer.
Wood, Robert Henry.

The following trasfers have also been effected by the Council:—

Associate to Graduate.

Hook, Herbert James.
Lord, Will.

Student to Graduate.

Adye, Arthur Francis C.
Allan, Robert Hector
Ashton, Hubert Fozard.
Atkinson, Cyril Nichdas.
Bailey, Herbert Gordn.
Bhavnani, Krishna Jhamatmal, B.Sc.(Eng.)
Birkett, George Willian A.
Blackburn, Sydney Charles.
Boyd, John Stenhouse.
Brown, William Edwarc.
Callaghan, Reginald Joseph.
Carter, Robert Owen.
Cliff, James Stanley.
Dow, David.
Durrani, Mohammad Salm K., B.Sc.(Eng.).
Edge, William.
Fareham, John.
Fuad, Ibraham.
Gowdridge, Francis.
Graham, Kenneth Alexander.
Gray, John, B.Sc.(Eng.).
Gupta, Chunni Lal, B.Sc.Tech.
Hayter, Desmond Edward
Hempsall, Cyril.
Hill, Francis Glynn.
Hill, Owen Clay.
Holmes, Victor Irving.
Jackson, John Benedict.
Justice, Charles Reginald.
Kitching, Philip Henry.
Konried, George Julius, B.Sc.(Eng.).
Larkin, Alfred Spencer.
Lillie, Herbert.
McIlvride, Keith Jack A.
Moore, Joseph Aubrey, B.Eng.
Morris, Merlin.
O'Dell, Eric Robert.
O'Farrell, George Callender, B.Sc.(Eng.).
Quinton, Harold Frederick, B.Sc.(Eng.).
Ratnam, Chelasani Venkata.
Ross, John, jun.
Stirrat, James.
Sutton, Ernest Joseph.
Thadani, Parmanand Tahilram, B.Sc.Tech.
Thorn, Donald Ainsworth, B.Sc.(Eng.).
Topham, Harry Bradley.
Turner, John Hill.
Vernon, John Russell, G.
Waddon, Ernest Avant.
Wijetilaka, Bennett.
Withers, Wyndham Webb, B.Sc.